ONE-YEAR POST-OPERATIVE STABILITY OF LEFORT I OSTEOTOMIES USING RESORBABLE FIXATION: A RETROSPECTIVE ANALYSIS OF DIVERSE FACIAL PATTERNS ON SKELETAL RELAPSE

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DISCLAIMER

The opinions expressed herein are those of the author and are not to be construed as those of the United States Air Force Dental Corps, United States Air Force, Department of Defense, or the United States Government.

DEDICATION

This thesis is dedicated to my beautiful wife, Christina, and our four wonderful children, Sydney, Keaton, Reese, and Jack. Without their continuing love, support, and encouragement, I would surely not have considered a return to school and the rigors of a post-graduate residency program.

I would be ungrateful if I did not also mention the positive influences of my father, Larry Stewart Wendfeldt, who is the exemplary father that I hope one day to become, and my mother, Mary Kaye, who has dedicated her life to caring for her three children and always insisted that we give our best effort in all that we do.

It has been a long haul, both professionally and educationally, and I owe my family much for their enduring patience. May our loving Heavenly Father bless their lives as we enter together into the rewarding world of orthodontics, the greatest specialty in all of dentistry.

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Lieutenant Colonel (Dr.) Kevin Kiely, Chief Collaborator, for patience, professional encouragement and guidance in seeing this project from a small dream to a completed reality.

ABSTRACT

ONE-YEAR POST-OPERATIVE STABILITY OF LEFORT I OSTEOTOMIES USING RESORBABLE FIXATION: A RETROSPECTIVE ANALYSIS OF DIVERSE FACIAL PATTERNS ON SKELETAL RELAPSE

Kyle Stewart Wendfeldt, D.D.S.

14 October 2002

The purpose of this retrospective study was to determine post-operative skeletal relapse of maxillary LeFort I osteotomies using fixation plates and screws composed of a bioabsorbable copolymer of poly-L lactic and poly-L glycolic acid. The quantity of skeletal relapse from pre-treatment to immediate post-operative to one-year after surgery was measured and compared between two groups of diverse facial patterns, long-faced dolichofacial subjects and short-faced brachyfacial subjects.

Twenty-three subjects, 18 dolichofacial and 5 brachyfacial, ages 19-39 were treated with LeFort I osteotomies to correct excess vertical maxillary height. Pre-operative, immediate post-operative, and one-year post-operative lateral cephalometric radiographs were traced and digitized.

A template of each pre-operative maxilla allowed a best-fit technique of superimposition to be utilized for measurement of and comparison with the immediate post-operative and one-year post-operative lateral cephalometric radiographs to horizontal (Frankfort horizontal) and vertical (Nasion perpendicular) reference planes. Linear millimeter measurements were recorded to the following four cephalometric landmarks: Posterior nasal spine (PNS), anterior nasal spine (ANS), A-point, and M-point. M-point is marked by visual inspection at the center point in the widest part of the premaxillary outline.

A two-factor repeated measures ANOVA (Wilks' lambda) was used to compare the magnitude of skeletal relapse one year after surgery within and between the dolichofacial and brachyfacial subjects. Significance for all tests was set at $p \leq 0.05$. Statistically greater post-operative relapse for PNS to Frankfort horizontal was found for all subjects evaluated for vertical stability. Antero-posterior relapse for all subjects was again only statistically significant for the point PNS. A statistically significant difference was found between the two facial types (dolichofacial vs brachyfacial) for PNS and A-point to Nasion perpendicular with brachyfacial subjects demonstrating more post-operative relaps. Further studies using larger sample sizes of diverse facial patterns are required to determine the precise role biomechanical efficiency plays in surgical relapse.

Although several values were found to be statistically significant for all subjects, the absolute values of post-operative relapse using bioabsorbable polymers was clinically negligible. The most significant contribution of this study to the volume of surgical stability literature is reporting the absolute magnitudes of post-operative relapse. The greatest relapse in any direction was 0.340 mm (PNS to Frankfort horizontal). The findings of this study demonstrate relapse tendencies in fractions of a millimeter which can perhaps be attributed to excellent surgical manipulation, fixation material, or both. Although several relapse values for this study may have been statistically significant the absolute magnitude was clinically insignificant. In fact, post-operative relapse was less than that previously published for rigid internal metallic fixation.

Bioabsorbable copolymers provide excellent post-operative stability for superior and anterior maxillary surgical repositioning that rivals stability measurements using rigid internal metallic fixation.

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CHAPTER I

INTRODUCTION

History of the Maxillary Osteotomy

Mobilization of the maxilla was first described in the European literature in 1859 (von Langenbeck, 1859). von Langenbeck made a horizontal cut, known as an osteotomy, partially through the maxillary bone above the apices of the maxillary teeth and termed it osteoplastic resection of the maxilla. Two years later he established the concept of temporary mobilization and inferior displacement of the maxilla by severing a majority of the maxilla away from the cranium in the horizontal plane at the level of the pterygopalatine fissure. An extraoral incision of the face extended bilaterally from the midline to the zygoma to expose the entire maxilla. The surgeon would then divide the maxilla horizontally and tilt it inferiorly, finally allowing it to remain tethered on its soft tissues to heal in the original position.

Surgical mobilization of the maxilla using bone chisels was described as early as 1867 in the American surgical literature by a Boston physician named David Cheever (Cheever, 1867). In 1901, the same fracture line used by Cheever would be described as the LeFort I position. He used this procedure to gain access to a nasopharyngeal tumor. After performing a hemi- maxillectomy Cheever discovered that the maxillae could heal and remain stable after being fractured down and replaced in its pre-surgical position.

Today the term downfracture is commonly used to describe this mobilization of the maxilla from the cranium. In 1870, Cheever performed the first total maxillary downfracture in the United States on another patient to again gain access to a large nasopharyngeal tumor (Fig 1 from Bosworth, 1889, p.14). After resecting the tumor, he successfully repositioned and secured the maxilla to the cranium with internal transosseous silver wires. The patient died five days after surgery from complications associated with his generally debilitated condition yet Cheever's accomplishment was viewed as a truly remarkable feat considering the state of surgery and anesthesia at the time.

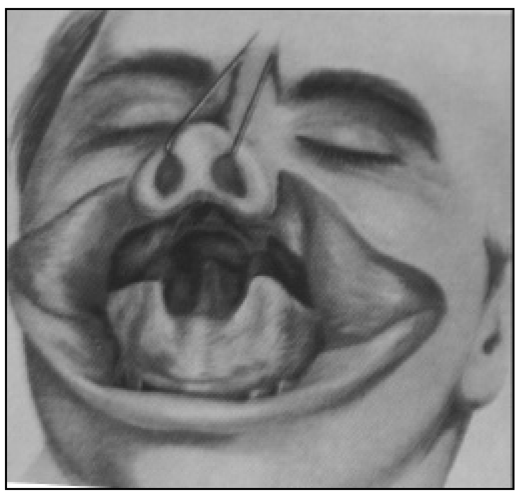

Fig 1 Cheever gained access to a nasopharyngeal tumor via extraoral incisions

In 1893, Lanz described an extension of the operation by von Langenbeck when he divided the maxilla down the midline antero-posteriorly and expanded along the midline to gain access to the pituitary fossa (Lanz, 1893). Today we call this procedure a two-piece LeFort I osteotomy.

In 1901, a French anatomist and surgeon named LeFort, studied patterns of facial fracture. To this very day his classification of traumatic maxillary fracture lines known as I, II, and III continue to describe how the facial skeleton is surgically altered (Fig 2 from Bell, 1985 p. 48).

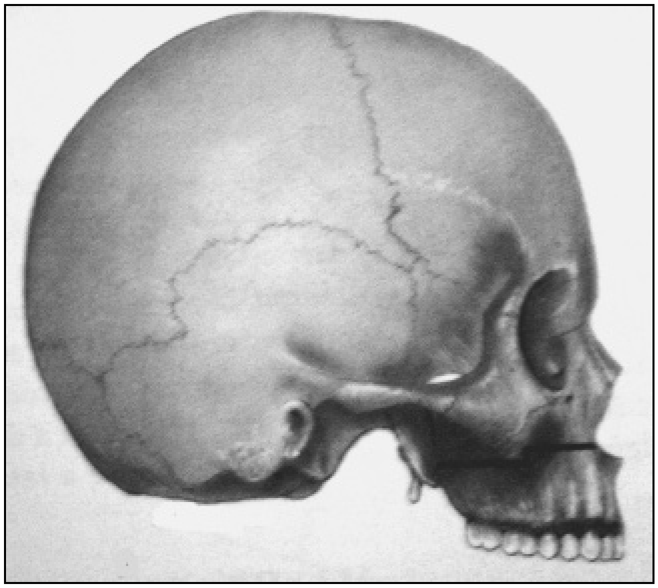

Figure 2 LeFort I fracture line

In 1927, Wassmund performed the first total maxillary osteotomy to correct a skeletal anterior open bite. Recognized as the first correction of midface malposition, he transversely fractured the maxilla with a chisel but did not cut through the pterygoid plates (Wassmund, 1927). He then used interarch elastic bands for 14 days to supply orthopedic traction to assist moving the tethered maxilla into the desired position.

Years passed as the total maxillary osteotomy fell out of favor due to high morbidity rates and relapse tendencies. It wasn't until 1952, however, that a revival in maxillary surgery occurred when an American surgeon named Converse reported advancing the maxilla with a total maxillary osteotomy. He advocated complete transection of the maxilla and palatine bones to enhance stability of the anterior movement and long-term retention.

Superior long-term results were reported by Obwegeser in 1969 primarily due to full mobilization of the maxilla via complete transection of the pterygoid plates of the sphenoid bone and maxilla that decreased soft tissue resistance and thereby improved stability (Obwegeser, 1969). Early fears over devascularization of facial tissues and devitalization of teeth have waned as surgical technique, hypotensive anesthesia, and procedures to control intraoperative bleeding have improved.

In 1969, research performed by Bell on rhesus monkeys laid much of the philosophical and physiologic foundation for the future success of the total maxillary osteotomy (Bell, 1969). Bell noted only transient ischemia, minimal osteonecrosis, and early osseous union when the maxilla was completely transected and attached only to the palatal mucosa (Bell, 1971). Clinical confidence in the total maxillary osteotomy procedure grew geometrically after the publication of Bell's research.

Long-term stability and therefore relapse following the total maxillary (LeFort I) osteotomy was a grave concern that puzzled surgeons and orthodontists throughout the 1970s and 1980s. In 1974, Willmar provided a detailed description of the changes in the maxilla following LeFort I osteotomy (Willmar, 1974). He also noted several factors that influenced post-operative stability including the direction and amount of maxillary movement, osteotomy design, adequacy of mobilization, type of stabilization, occlusal interdigitation, and the use of synthetic or organic interpositional bone graft materials.

Over the past thirty years clinicians and research scientists have collaborated to provide an impressive volume of literature on the total maxillary osteotomy to the surgical and orthodontic communities. This paper will address clinical indications, techniques, methods of fixation, and factors affecting stability and relapse of the total maxillary osteotomy that have received attention in the literature.

Indications for the Maxillary Osteotomy

Surgical correction of the maxilla with a total maxillary osteotomy at the LeFort I level has been used to correct a variety of dentofacial deformities. Most commonly the procedure is used to correct skeletal deviations that manifest themselves as extremes of dental malocclusion. The different groups for which the LeFort I osteotomy is indicated can be skeletal deep or open bite types combined with any of Angle's original classifications of dental Class I, II, or III malocclusion (Angle, 1900). Most commonly, the LeFort I osteotomy is used to correct skeletal open bite, skeletal Class III anterior cross-bite, and idiopathic hyperdivergent "long-faced" syndrome otherwise known as total maxillary alveolar hyperplasia or vertical maxillary excess. Although a multitude of bony segments and trajectories can be used, the total maxillary osteotomy predominantly repositions the maxilla superiorly and anteriorly to correct the three clinical presentations noted above. Oral surgeons refer to the procedure as an "impaction and advancement".

Maxillary Osteotomy Surgical Technique

Down-fracturing the maxilla simplifies the myriad of surgical procedures that can be performed on the maxilla by allowing access to all parts of the bony anatomy of the maxilla (Epker and Wolford, 1976). A horizontal incision is made in the depth of the maxillary vestibule from right to left zygomatic buttresses (Epker and Schendel, 1980). The surgeon then dissects posteriorly beneath the periosteum to the pterygoid plates of the sphenoid bone, then to the infraorbital region of the maxilla superiorly and into the nasal cavity anteriorly (Fig 3 from Epker, 1980, p.6).

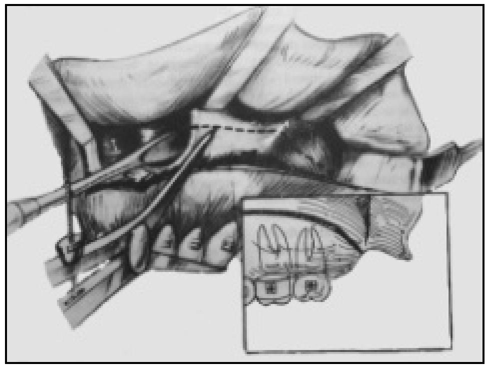

Fig 3 LeFort I surgical dissection from nasal piriform aperature to pterygoid plates

The lateral and medial walls of the maxilla, nasal septum, and vomer are then transected with a high-speed bur or reciprocating saw blade at least 4 mm above the apices of the maxillary teeth and irregularities of bone and nasal septum are removed to allow passive repositioning of the mobilized maxilla. The cut is carried from the nasal piriform aperature to the pterygoid plates posteriorly (Fig 4 from Bell, 1985, p. 37).

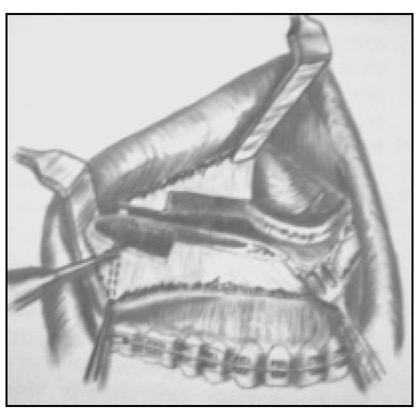

Figure 4 Surgical cuts from nasal piriform aperature through the pterygoid plates

Lateral ostectomy is sometimes carried inferiorly just distal to the maxillary second molar tooth (Wolford and Epker, 1975). The nasal septum is separated from the maxilla and will now down-fracture with finger pressure applied to the anterior maxilla (Fig 5a from Bell, 1985, p. 27) or mobilized and repositioned with disimpaction forceps (Fig 5b from Epker, 1980, p. 6).

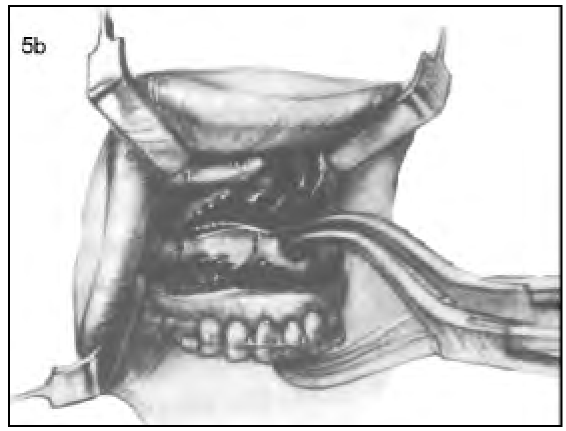

Fig 5a (left) Mobilization of the maxilla using finger pressure or Fig 5b (right) disimpaction forceps

The mobilized maxilla is then stabilized across the osteotomy site with one of three types of fixation systems. The oldest method utilizes stainless steel surgical suspension wires similar to those seen in Figure 6 below (Rosen, 1986, p. 748).

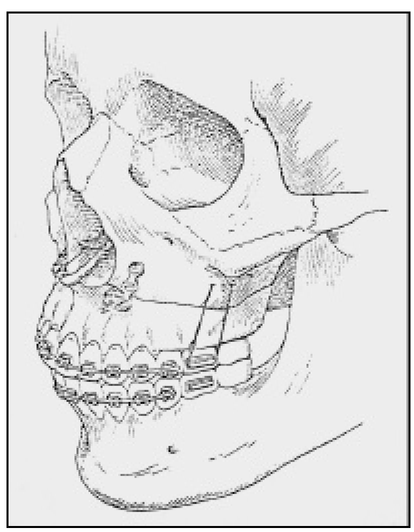

Fig 6 Maxillary osteotomy fixation using metallic L-plates and suspension wires

Second, titanium alloy metallic screws and fixation plates have been popular with oral and maxillofacial surgeons since the early 1980s. Third, plates composed of bioabsorbable polymers are secured across the osteotomy site with identical composition bioabsorbable screws (Fig 7 from Kiely, 2002, original photo).

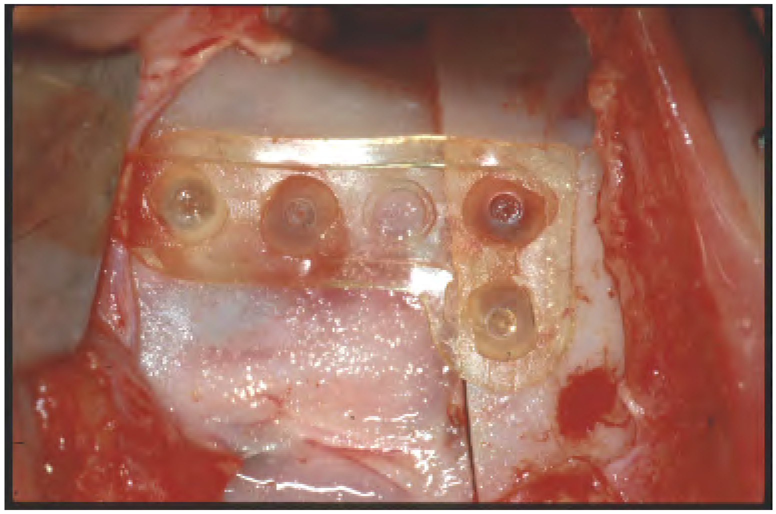

Fig 7 Maxillary osteotomy fixation using bioabsorbable L-plates and screws

Post-operative Fixation of the Maxillary Osteotomy

The original maxillary osteotomies performed by von Langenbeck and Cheever were not stabilized across the osteotomy site with any material. These early surgeons chose not to stabilize the osteotomy segments together perhaps because the maxilla was not completely transected. Surgical improvements by Converse dictated stabilization across the osteotomy site to immobilize the transected maxilla (Converse and Shapiro, 1952). Wire osseous fixation with stainless steel wires was used to approximate the bony segments to limit post-operative mobility and encourage osseous union. Stainless steel wires were passed through holes drilled into each segment and cinched tight. Although initial victories in surgical technique were reported by Converse, it wasn't until 1959 that the first reported superior movement of the maxilla was attempted (Schuchardt, 1959).

In 1969, Bell published a landmark paper on microangiographic and histologic studies demonstrating complete sectioning of the perpendicular plates of the palatine bone did not excessively compromise the blood supply and more extensive posterior osteotomies could be performed (Bell, 1969). Greater knowledge of collateral blood supply healing at the osteotomy site dramatically improved surgical technique and post-operative stability (Bell, 1971). During the 1970s and 1980s numerous favorable reports appeared in the orthodontic and surgical literature demonstrating clinically acceptable relapse measurements with superior repositioning of the maxilla (Fish et al,1978).

Longitudinal stability studies on the one-piece LeFort I osteotomy impaction and advancement by Phillips, Proffit, and Turvey (1987) revealed 2 mm relapse as a clinically acceptable threshold when using wire osseous fixation. Carpenter, Nanda, and Currier (1989) found no difference in post-operative relapse of one-piece LeFort I osteotomies when they compared groups stabilized with wire osseous fixation with rigid internal metallic fixation (RIF) plates and screws. More recently Egbert et al found a statistically significant difference in vertical and horizontal relapse of one-piece LeFort I osteotomies between wire osseous fixation and rigid internal metallic fixation plates and screws (1995). The group stabilized with rigid internal metallic fixation plates and screws demonstrated only one-half the relapse of the wire osseous fixation group in the vertical plane and statistically improved stability in the horizontal plane. Advancements in surgical techniques and fixation materials have profoundly changed and improved relapse rates of one-piece LeFort I osteotomies, and thus appear to contradict earlier reports.

Although variability is highly likely to occur between different surgeons and surgical centers, all trends reported in the surgical and orthodontic literature demonstrate the superiority of rigid internal metallic fixation plates and screws to wire osseous fixation materials. Rigid internal fixation materials are considered by most oral and maxillofacial surgeons to be the "gold standard" for post-operative stability in orthognathic surgery.

Since the early 1990s, laboratory and clinical research has developed, tested, modified, and re-examined stabilizing the facial skeleton with biologically tolerable polymer materials that begin degradation after union occurs across the osteotomy site. These polymers are termed resorbable or bioabsorbable. Numerous laboratory tests show great promise for this group of resorbable polymers in sheer and compression strength (An et al, 2000), fatigue resistance (Wiltfang et al, 2000), and fracture toughness (Araujo et al, 2001) compared to rigid internal metallic fixation systems. Longitudinal clinical reports of their favorable use in mandibular orthognathic surgery have been published by Edwards, Kiely, and Eppley (1999), Turvey et al (2002), and Ferretti and Reyneke (2002). No research to date has published longitudinal results of post-operative stability using resorbable fixation for one-piece impaction and/or advancement maxillary surgery. The purpose of this paper is to report original research on the stability of one-piece LeFort I impaction with and without advancement osteotomies using resorbable plates and screws as the only method of post-operative fixation. Using the results from this and other longitudinal studies, oral and maxillofacial surgeons may soon replace rigid internal metallic fixation systems with resorbable polymers for all orthognathic surgeries. Further investigation may define bioabsorbable polymers as the new "gold standard" for orthognathic surgical procedures.

Post-operative Stability of the Maxillary Osteotomy

The key element in orthognathic surgery is not necessarily the magnitude of the surgical move nor the trajectory, but the amount of long-term relapse. After all, who would volunteer for a painful, moderately incapacitating, and temporally disfiguring elective surgical procedure to their face knowing in advance that relapse would negate the surgical movement. An utter failure. Schendel and Epker noted unacceptable post-operative stability more frequently with large advancements (greater than 10 mm) and that most of the relapse occurred during the first 6-8 weeks after surgery (1980). Termed early relapse, this type usually occurs at the osteotomy site due to inadequately immobilized segments. Gassamann proposed that large advancements place increasing amounts of stretch on the surrounding soft tissue envelope and is compounded by a decreased hard tissue surface area interface along the osteotomy line to resist soft tissue stretch relapse movements shortly after surgery (1990).

Larsen et al noted there was very little difference between maxilla stabilized by plates and those stabilized by wires (1989). However, they included a variety of surgical moves in their two groups. Maxillary stability cannot be studied without examining the trajectory of the movement initially attempted at the time of surgery. Most of the literature agrees that superior repositioning of the maxilla, termed an impaction, is a very stable movement. Proffit, Phillips, and Turvey noted that the vertical position of the maxilla was stable in 80% of patients who underwent impaction with wire osseous fixation (1987). Carlotti and Schendel studied 30 patients who were stabilized with wire osseous fixation for maxillary advancements (1987). Nearly 33% of the patients had unfavorable relapse and they recommended rigid internal fixation in cases of maxillary advancement up to 11 mm.

Therefore, in order to prevent relapse most orthognathic surgery research has reported on improvements in surgical technique using various types of interpositional graft materials and fixation systems. Most informative to the oral and maxillofacial surgeon and orthodontist have been longitudinal stability studies comparing fixation materials which showed promise in laboratory tests.

Diverse Facial Patterns

A comprehensive study of surgical stability would be incomplete without considering how the functional factors acting upon the osteotomy site influence relapse. Three separate experiments clearly demonstrate direct changes in bone shape due to the environmental stimuli of the surrounding musculature (Shapiro, 1934), (Washburn, 1947), (Avis, 1961). Epker and O'Ryan suggest how extreme functional patterns performed with enough intensity, duration, and frequency can biomechanically influence dysmorphic facial patterns (1982). The masticatory muscles in long-faced dolichofacial individuals are oriented in a more posterior and biomechanically inefficient pattern. Long-faced persons, therefore, generate smaller (50 lb) molar masticatory forces than short-faced brachyfacial individuals who display opposite morphological features and thus generate heavier molar (150-250lb) masticatory forces. Takada, Lowe and Freund (1984) infer that obliquely inclined and posteriorly positioned masseter muscle fibers relative to the occlusal plane may explain why long-faced dolichofacial individuals achieve their characteristic facial appearance.

Haskell, Day, and Tetz (1986) resolved vector forces from human cadavers with diverse dolichofacial and brachyfacial skeletal patterns. A computer generated model assisted in determining that the relative spatial muscle orientations in the two diverse facial types were different due to the variation in facial morphology and that this difference shows how much more efficient brachyfacial individuals are at generating simple bite forces. Most important to this discussion on the magnitude of surgical relapse is the following comment from Haskell, Day, and Tetz (1986, p. 380) “It is possible that through such analyses, the stresses present in the jaws of diverse mandibular forms may aid in the treatment planning of surgical procedures. Orthognathic sagittal advancements of the mandible that occasionally fail in long-faced persons may be the result of a bony incision unknowingly placed through areas of high stress as pictured in the FEA or caused by inadequate fixation in a highly stressed area prone to relapse as a result of biomechanical failure”. Bite forces were recorded in 35 patients treated for mandibular angle fractures and compared to 29 adult male controls (Tate et al, 1994). Molar bite forces on the fractured side were significantly less than controls and the contralateral side for the first six weeks after surgery indicating that the recommendations for the amount of post-operative fixation be reduced.

It was with great anticipation that we examined the following data set of post-operative maxillary stability. Understanding all biomechanical influences of diverse facial types on the post-operative maxilla could surely gird us with the knowledge of possible relapse phenomena as in the mandible. Oral and maxillofacial surgeons could then appropriately design fixation measures to counteract adverse functional forces created by diverse facial types and thereby limit the magnitude of post-operative relapse.

Study Objectives

The primary objective of this study was to evaluate the magnitude of skeletal relapse one year after superior and/or anterior surgical movement of maxillary LeFort I osteotomies using fixation plates and screws composed of a bioabsorbable copolymer of poly-L lactic and poly-L glycolic (PLLA/PGA) acid.

A second objective of this study was to assess and compare differences in skeletal relapse between two diverse facial and skeletal patterns receiving similar surgical procedures.

Study Hypotheses

Null Hypotheses:

1. There is no difference in relapse values when comparing post-operative stability of maxillary LeFort I impaction and/or advancement osteotomies stabilized with a bioabsorbable copolymer composed of poly-L lactic/poly-L glycolic acid and previously published data of osteotomies stabilized with metallic rigid internal fixation.

2. There is no difference in relapse values when comparing post-operative stability of maxillary LeFort I impaction and/or advancement osteotomies between dolichofacial and brachyfacial patterns.

CHAPTER II

REVIEW OF THE LITERATURE

Post-operative Fixation Materials

The original maxillary osteotomies performed by von Langenbeck (von Langenbeck, 1859) and Cheever (Cheever, 1867) allowed the maxilla to float freely after surgery. No fixation materials were used to reposition the maxilla. Bony union occurred wherever the maxilla was held the longest. Concerned primarily with recurrence of tumors, surgeons made no mention of the functional or esthetic position of the post-operative maxilla.

In the 1960s Obwegeser described post-operative fixation of total maxillary osteotomies with surgical suspension wires (Obwegeser, 1969). After complete mobilization at the LeFort I level, holes were drilled on either side of the osteotomy site and stainless steel suspension ligature wires were threaded through and cinched tightly (Fig 8 from Bell, 1985, p. 50)

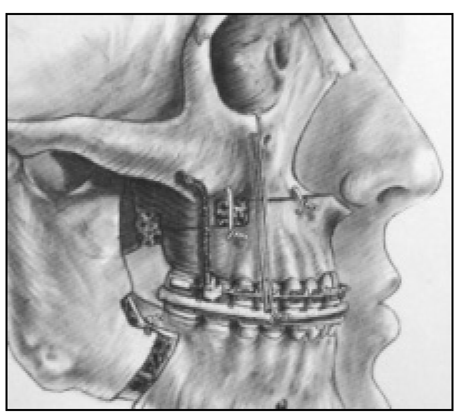

Fig 8 Maxillo-mandibular fixation with inter-occlusal splint and suspension wires

Michelet introduced metallic fixation plates and screws in 1973 to stabilize the post-operative maxilla (Michelet, 1973). Few technological advancements have propelled the field of orthognathic surgery forward like rigid internal metallic fixation systems. Titanium alloy plates and screws like those seen in Figure 9 below span the osteotomy site and thus rigidly holds the inferior segment composed of maxillary alveolus and maxillary teeth to the superior segment of the maxilla.

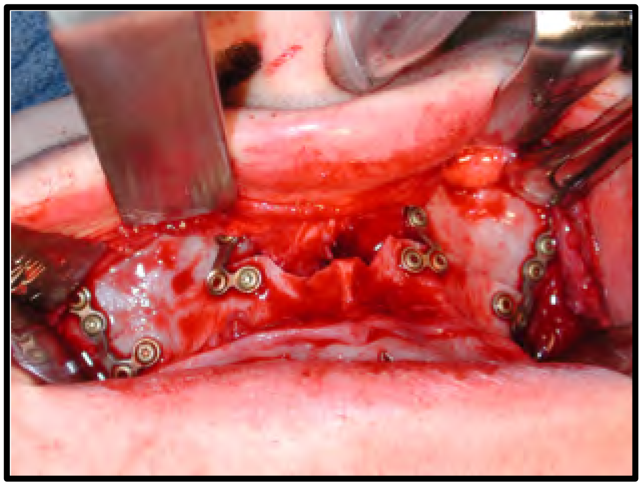

Fig 9 Metallic fixation after maxillary osteotomy

Stabilized with rigid internal fixation plates the mucosa is closed over the osteotomy site making maxillo-mandibular fixation (MMF) unnecessary. This relatively simple application of rigid internal metallic fixation plates and screws expedites masticatory rehabilitation, improves esthetic outcomes, and allows more complete surgical reconstructions (Epker and Schendel, 1980). The use of rigid internal metallic fixation is so superior in post-operative stability and ease of placement that few surgeons would return to using wire suspension ligatures. Rigid internal metallic fixation of the craniofacial skeleton is clearly the gold standard by which all future materials will be measured against (Araujo et al, 2001). Advancements in size, geometric shape, and placement methods of metallic fixation systems have exploded since the early 1980s and virtually any conceivable application can be performed in the craniofacial skeleton with rigid internal metallic fixation. Why, then, should we consider exploring alternatives?

First, metallic devices permanently implanted in the human body are not without complication. Metallic devices may require removal due to loosening, migration, dental impingement, interference with the maxillary sinuses leading to sinus infections, palpability through the skin of the face, thermal sensitivity, latent foreign body reactions and infections, and patient's psychological desire to eliminate artificial hardware (Schmidt et al, 1998). This retrospective study of 39 patients reported 11.1% had at least a portion of their metallic rigid internal fixation hardware removed because they either requested removal or required removal secondary to complications related to the plate or screw (1998). The reasons cited for removal included radiographic obstruction, pain, palpability by the patient, sinusitis, temperature sensitivity, infection, growth restriction, and patient request due to objection of having a foreign body remain in their facial region. Are we certain that the metals used in modern orthognathic surgery today are entirely biologically inert?

Particulate matter in the surrounding bone and soft tissues have been reported since the early 1970s. Histopathological samples were taken from 44 patients after orthopedic surgery procedures with metallic implants and were subjected to optical microscopy, electron microscopy, electron diffraction, and x-ray spectrographic examination by trained pathologists (Winter, 1974). Corrosion of the metallic implants led to the formation of soluble and insoluble compounds that the immune system recognizes as foreign bodies. 13 of the 44 patients Winter examined demonstrated granulomatous inflammatory reactions composed of groups of large macrophages called multinucleate giant cells. Electron diffraction study determined the particles were carbides of chromium known to be cytotoxic. Winter (1974) also noted that the soft tissues were frequently impregnated with metallic deposits leaving the tissue to appear necrotic. Similar black metallic particles are also seen under histopathological analysis with modern day titanium alloy based rigid internal fixation systems used in orthognathic surgery (Kim et al, 1997), (Matthew and Frame, 1998), (Hirai et al, 2001).

There is evidence that chronic and sustained immune responses to titanium are clinically documented (Hunt et al, 1994), (Ungersboeck et al, 1995). Katou examined biopsy specimens from 12 patients taken from 17 mandibular fracture sites between 24 to 96 weeks after open reduction with titanium miniplates (Katou et al, 1995). Chronic inflammation of a delayed-type hypersensitivity reaction was shown with a greater proportion of CD4+ inducer cells than CD8+ suppressor cells. The debate about routinely removing all metallic fixation plates at some point after surgery should include the issue of hypersensitivity.

Normal stress patterns are disrupted and primary bone callus formation is altered after fracture fixation with metallic fixation. Seventeen weeks after fixation with metallic plates and screws, haversian canals demonstrated enlargement and collagen bundles were disrupted leading to evidence of osteoporosis, bone atrophy, and some refractures (Paavolainen et al, 1978). It is for this reason that metallic devices cannot be used in growing children. The same property that makes them ideal for post-operative stability, namely rigidity, does not allow for proportionate growth of facial structures near the osteotomy site (Epply and Reilly, 1997). Surgical instability is easily witnessed in pediatric cranial reconstruction due to the migration of metallic fixation plates as the child grows (Papay et al, 1995), (Imola et al, 2001).

Progress has never been made in any endeavor, particularly orthognathic surgery by accepting the status quo. Our goal should be to safely and effectively reposition and restore the facial bones with limited facial scars, artificial materials, and hard or soft tissue dysfunction. Excellent post-operative stability and esthetics without permanently implanted hardware is clearly a lofty goal that benefits both the patient and the healthcare system. In an effort to address the issues of permanency, growth restriction, interference with radiography, palpability, thermal sensitivity, hypersensitivity, and psychological desire for removal (Schmidt et al, 1998), a new class of biomaterials, bioabsorbable polymers, are being honed for use as internal fixation devices following orthognathic surgery. Reluctance to try bioabsorbable polymers is perhaps due to the difference in how they handle intra-operatively or the lack of long-term stability data until recently (Turvey et al, 2002).

The ideal bioabsorbable material allows internal (beneath oral mucosa) fixation to be designed with appropriate early strength to meet the relapse intensive demands of the first six to eight weeks after surgery yet will degrade in a predictable manner so that adequate strength remains to stabilize the bony segments while osseous union occurs (Pietrzak, 1997). Additionally, no adverse inflammatory responses should occur that would require surgical removal. Finally, the ideal bioabsorbable material should eventually break down entirely so that radiographic obstruction, palpability, temperature sensitivity, and psychologic issues are resolved (Eppley et al, 1996).

Bioabsorbable polymers, designed to gradually lose strength after implantation and be removed from the body, are positioned to become the new “gold standard” for post-operative fixation in orthognathic surgery. Polymers are composed of macromolecular monomers of repeating units up to 1 million daltons in molecular weight resembling the links in a chain (Suuronen et al, 1992). When two or more homopolymers (-AAAAAAAAA-) are connected, a copolymer (-AAAABBBAAAAAABBB-) is formed with different physical properties than its constituents. An amorphous microstructure has polymer chains loosely packed and randomly oriented in three dimensions with respect to each other. Amorphous regions can easily glide past each other and therefore result in relatively weak chemical bonds (Stryer, 1989). Crystalline regions are closely packed parallel chains of polymers that exhibit high strength chemical bonds due to hydrogen bonding and van der waals interactions between polymer chains. Larger crystalline chain, and thus molecular weight, copolymers increase the bulk and strength of the polymer chains because they prevent amorphous regions of the polymer chains from slipping past each other. Therefore, increasing the crystallinity of a copolymer increases its strength, especially if a load is applied rapidly. Higher crystallinity also increases its degradation time.

Bioabsorbable materials degrade in two phases. Phase one hydrolytically breaks apart the long polymer chains into short polymer chains. Hydrolysis reduces the molecular weight and strength as the polymer chains slip past each other (Pietrzak, 1997). Highly amorphous polymers are easily attacked by hydrolysis and resorb quickly. Highly crystalline polymers on the other hand resorb slower and decrease the surrounding tissue pH which can incite local inflammatory reactions. Phase two is a physiologic response of phagocytic macrophages engulfing polymer chains and metabolizing them to carbon dioxide and water via the Krebs cycle, thereby radically diminishing the mass of the implant. Initially, an inflammatory reaction encircles the implant, then a thin fibrous membrane forms, and finally bone fills in after final degradation of the copolymer plates and screws.

Bioabsorbable fixation systems for orthognathic surgery have included polydioxanone (PDO), polyglygonate, pure polyglycolic acid (PGA), pure poly-L-lactic acid (PLLA), and PGA/PLLA copolymers. PDO and PGA have shown the least strength under tension (Miller et al, 1977). PGA homopolymers have demonstrated the greatest strength yet PGA resorbs very quickly despite its high crystallinity. PGA loses most of its strength in 4 weeks and all of its mass in 6-12 months (Tormala, 1993). As mentioned above, large quantities of acidic glycolic acid can be released into the surrounding tissue decreasing the pH to incite local inflammatory reactions (Tormala, 1993).

Alternatively, pure PLLA absorbs in 24-36 months due to its numerous cross-linked crystalline regions and has been shown to incite latent foreign-body macrophage reactions up to 5.7 years after implantation (Bergsma et al, 1995). PLLA miniplates have demonstrated effective fixation in mandibular fractures (Beesho et al, 1997) and unstable zygomatic fractures (Bos et al, 1987). PLLA effectively stabilized all nine patients in a post-operatively stability study by Bergsma for two years, yet four of the nine returned with nonspecific foreign body macrophage reactions three years after orthognathic surgery (Bergsma et al, 1993). Although no osteolytic changes were found in the cortical bone and all fracture lines were no longer detectable, electron microscopic analysis revealed crystalline-like PLLA material within macrophages. As several authors have reported, hydrolysis of PLLA requires approximately 24-36 months which breaks the material up into small crystal-like fragments of various sizes for macrophage degradation (Miller et al, 1977), (Chu et al, 1982). This change in the shape and biomechanical properties of PLLA during degradation intensifies foreign body reactions (Sevastjanova et al, 1987) in a similar manner to rigid internal metallic fixation implants.

The first commercially available bioabsorbable fixation system approved for orthognathic surgery by the US Food and Drug Administration is a copolymer of PGA and PLLA, termed Lactosorb^{R} (Lorenz/Biomet Inc. Warsaw, IN). Lactosorb^{R} is a random, linear copolymer of 82% PLLA and 18%PGA with mostly amorphous regions and very similar in composition to the popular resorbable Vicryl^{R} (Ethicon Corp. San Angelo, TX) suture material used by all surgeons. Lactosorb^{R}, between PGA and PLLA in physical properties demonstrates adequate strength for the relapse intensive six weeks immediate post-operatively. The peak flexural load of Lactosorb^{R} in-vitro exceeded that of a 1.5 mm titanium fixation plate in an 8-week buffered saline test (Pietrzak, 1996). Bos reported the bending modulus of PLLA plates (5 GPa) to be equivalent to metallic Champy plates (5-7 GPa) with stable fixation of zygomatic fractures three months after surgery (Bos et al, 1987). Additionally, Bos found no signs of inflammation or foreign body reaction were found during the three month observation period. More recently, the screw holding strength of bioabsorbable screws was tested to measure the efficacy of fixation. The PLLA/PGA copolymer Lactosorb^{R} demonstrates a 112.9 ± 12.1 N single screw pull out force (Tiainen et al, 2002). Even though masticatory loads are complex combinations of torsional movements the combined strength of multiple bioabsorbable bone plates and screws across a fracture or osteotomy site appears more than adequate to offset typical 100N molar masticatory bite forces (Tate et al, 1994).

A detailed in-vitro strength analysis by Araujo et al (2001) compared two types of commercially available rigid titanium fixation systems to two commercially available bioabsorbable systems after LeFort I osteomy on a dry skull. Applied loads in the antero-posterior (AP) direction were designed to simulate relapse forces while applied loads in the infero-superior (IS) direction simulated biting forces. IS load directions were found to be significantly different than AP load movements. Metallic plates demonstrated less load deflection deformation than bioabsorbables in AP direction yet no significant difference was found between the groups in the IS direction. Failure analysis tests revealed greater gap widening in the posterior region than the anterior region for the titanium fixation groups. Although bioabsorbable materials deform earlier and resist permanent deformation less than their metallic counterparts, other authors report bioabsorbables possess adequate load capacity for clinical conditions (Song et al, 1997). Araujo et al (2001) conclude, “based on these biomechanical results resorbable fixation should be considered adequate for fixation in maxillary surgery”.

Bioabsorbable fixation is an attractive alternative to metallic fixation in pediatric craniofacial surgery due to its impressive strength during the initial phases of healing (An, 2001). Most impressive is the property of natural degradation that does not impede normal growth. A ten-month follow-up study of 35 pediatric craniofacial reconstruction patients reported no complications involved with wound healing, contour, or stability (Montag et al, 1997). A separate study demonstrated satisfactory post-operative wound healing in 21 out of 22 pediatric craniofacial surgery patients and recommended resorbable fixation as an attractive option in pediatric plastic and craniofacial surgery (Kumar et al, 1997). Long-term efficacy of bioabsorbable fixation was also reported by Imola et al (2001) when 52 of 54 pediatric patients demonstrated uncomplicated bone healing and adequate osseous union after stabilization with bioabsorbable fixation. Imola concludes that the outcomes of their study are comparable to results using metal osteosynthesis in similar surgical situations yet bioabsorbables are a, “means of avoiding the potential and well-documented problems with rigid metal fixation and we believe the benefits are well worth the effort and represent a major advance in pediatric craniofacial surgery.”

The resorption characteristics of bioabsorbable fixation systems appear to be slow enough to offer adequate stabilization while not overwhelming the local ability to clear degradation products (Eppley, 1997). In-vivo fixation of parietal bone craniotomies of 20 rabbit skulls with 2.0 mm Lactosorb^{R} plates and screws revealed no change in implant size with completely intact plates and screws after two months, 66% reduction in cross-sectional dimension after 6 months, and approximately 99% reduction in cross-sectional dimension after 9 months (Eppley, 1997). Eppley and Reilly (1997) conclude that, “no evidence of macromolecular polymer debris could be found one year after surgery and that no contraindications for the clinical use of this specific formulation of PLLA/PGA copolymer could be found for implantation on craniofacial bone surfaces”. Lactosorb^{R} entirely clears from the body one year after surgery due to its faster resorption than pure PLLA, therefore, copolymers of PLLA and PGA are well tolerated by the body (Habal, 1997). Due to their low crystallinity the potential for latent foreign body reactions is greatly diminished (Eppley et al, 1996).

In-vitro exposure of Lactosorb[R] copolymer to low but clinically therapeutic doses of ionizing radiation (80Gy) over an eight week period had no effect on the degradation properties of the material, thereby preventing the formation of small crystalline substances known to incite local inflammatory reactions (Pietrzak, 2002). Therefore, because metallic fixation may cause stress shielding and alter dosage requirements for therapeutic tumor radiation (Postlewaite et al, 1990) and because Lactosorb is tissue equivalent to radiotherapy beams (Rozema et al, 1990), Lactosorb[R] can therefore be used safely as internal fixators when ionizing radiation is necessary to eliminate maxillofacial tumors (Pietrzak, 2002).

Post-operative Stability of the Maxillary Osteotomy

Relapse following maxillary superior repositioning has been found to be relatively minor when good bony contact is maintained. Schendel reviewed 18 patients who had undergone maxillary impaction for vertical maxillary excess (Schendel, 1976). Cephalometric analysis 14 months post-operatively revealed a tendency of the maxilla to further intrude during the period of maxillo-mandibular (MMF) wire fixation. The greatest amount of intrusion was seen in the anterior maxilla at A-point with excellent stability found in both open bite and non-open bite cases.

In 1977, Bell and McBride analyzed the results of 41 patients with vertical maxillary excess treated by Le Fort I osteotomy and noted a slight tendency for the maxilla to intrude or retrude during MMF, but found that all cases were stable 13.5 months post-operatively, regardless of the presence or absence of open bite malocclusion (Bell, 1977). Phillips et al (1985) evaluated 60 patients who underwent superior maxillary repositioning, with and without segmentalization, and again reported minor superior relapse of the maxilla during fixation. In 1987, Proffitt et al studied 61 patients one year following maxillary impaction surgery for vertical maxillary excess. All patients were stabilized post-operatively with MMF. The posterior maxilla was stable in 87% of the cases and the anterior maxilla was stable 70% of the time during the MMF period. The relapse occurred in the superior direction. When the maxilla was moved superiorly, it could be expected to move further upward during the first six weeks after surgery if it moved at all. Additionally, between six weeks and one year post-operatively, 25% of the patients demonstrated more than 2 mm of inferior relapse movement of the anterior maxilla.

Four years later, 49 patients who underwent maxillary advancement to correct maxillary antero-posterior deficiency were followed (Proffit et al, 1991). Thirty-one patients were stabilized post-operatively with internal wire osteosynthesis and MMF while 18 patients had internal fixation with rigid titanium fixation plates. 80% of the patients had excellent stability at one year, while 20% had 2-4 mm of posterior movement of the anterior maxillary landmarks. No difference in antero-posterior stability between wire MMF fixation and internal rigid titanium fixation was found.

Stability data from numerous authors (McNeill et al, 1973), (Luyk and Ward-Booth, 1985), (Bishara et al, 1988), (Ellis et al, 1989), (Larsen et al, 1989), (Louis et al, 1993), (Bailey et al, 1994), and (Egbert et al, 1995), have found internal rigid titanium fixation to be equivalent or superior to both MMF wire fixation and internal wire osteosynthesis fixation. Fifteen patients with skeletal plus dental MMF versus 15 patients stabilized with rigid internal metallic fixation were evaluated by Skoczylas et al for potential effects of mandibular surgery on maxillary stability (1988). The authors found greater variability in the post-operative stability of those patients fixated with MMF than those stabilized with rigid internal metallic plates. Egbert et al demonstrated that 10 of 13 patients stabilized with internal rigid titanium fixation had less than 1mm post-operative horizontal change after maxillary advancement while only 6 of 12 patients stabilized with wire osteosynthesis achieved the same result (1995). He also reported the mean one-year post-operative relapse was 5.8% for the internal rigid titanium fixation group versus 13.8% for the MMF wire fixation group.

Post-operative migration or relapse of osteotomy segments stabilized with titanium miniplates were examined by Wall et al and no correlation was found between the magnitude of surgical movement and post-operative relapse (1998). The tendency toward further superior movement agrees with earlier findings by Proffit et al (1991). Wall et al concluded that titanium mini-plates do not prevent post-operative migration of the osteotomy segment…and post-operative migration of the osteotomy segment indicates that predictions of individual outcomes of surgical corrections are uncertain (1998). The majority of post-operative relapse has been attributed to the first six weeks following total maxillary osteotomy. Hoffman and Moloney (1996) reported mean relapse of 0.22 mm $\pm$ 0.19mm in the first six weeks after surgery for a group of fifteen patients with average 8.76 mm $\pm$ 0.99mm maxillary advancement.

There has been a strong trend since 1985 toward internal rigid fixation. Numerous studies have demonstrated improved bony healing, improved functional adaptation, decreased frequency of temporomandibular joint dysfunctions, and improved ability of patients to thrive when the maxilla and mandible were not immobilized post-operatively with MMF (Larsen et al, 1989). Adverse effects on respiration were shown in patients immobilized with MMF (Kohno et al, 1993). Forced vital capacity decreased 7.3 percent and forced expiratory volume in one second decreased 20.3 percent before and after MMF.

According to the clinical studies describing improved stability and functional considerations noted most oral and maxillofacial surgeons have nearly abandoned MMF. Related reports by the same authors have shown that patients overwhelmingly dislike and increasingly refuse to have their jaws wired shut for 4-8 weeks post-operatively. Even though this amount of time is necessary for bony union to occur with MMF, technical advances in internal rigid fixation makes the practice of “wiring the jaws shut” obsolete.

Despite the improved stability and patient acceptance of internal rigid metallic fixation, one disturbing biological response has been reported frequently, latent foreign body reaction and infection. Histological samples from 14 patients were gathered 7.5 to 17.5 months after mandibular fracture healing (Hirai et al, 2001). The specimens were gathered from bone adjacent to internal rigid metallic fixation plates only if the screws and plates could be removed without injuring adjacent structures. Black titanium particulate matter and multi-nucleated giant cells resembling macrophages were found in the bone and soft tissues near the bone plates and screws.

Advances in resorbable polymers have revitalized interest in resorbable fixation devices in craniofacial surgery (Suuronen et al, 1992). Successful fixation case reports by Eppley in 1995 of traumatic midface and calvarial fractures using a resorbable copolymer of poly-L Lactic acid and poly glycolic acid (PLLA/PGA) provided the stimulus for other surgeons to utilize the material in other craniofacial fixation circumstances (Eppley, 1996). In 1997, Goldstein reported on the use of resorbable fixation with PLLA/PGA in 8 patients treated with bifrontal craniotomies to correct craniosynostosis and one encephalocoele (Goldstein, 1997). No peri-operative or post-operative infections or complications were observed. Surgical segments were stabilized for the duration until bony union occured and most importantly growth restriction commonly seen with rigid titanium fixation plates was not observed.

In 1999, Westermark demonstrated reliable 2-year post-operative stability using PLLA/PGA resorbable fixation for 20 patients receiving elective bilateral sagittal split osteotomies of the mandible (Westermark, 1999). No adverse tissue reactions, clinical, radiological, or histological signs of healing complications were found.

In 2000, Shand and Heggie reported similar positive results for 31 patients using resorbable fixation with PLLA/PGA for a variety of routine maxillofacial repositioning procedures that were traditionally stabilized with internal rigid titanium fixation (Shand, 2000). Follow-up at 6 weeks revealed stability within normal limits. The authors concluded that resorbable fixation with PLLA/PGA is satisfactory for maxillo-mandibular repositioning.

The biomechanical characteristics of metallic and resorbable polymeric fixation systems using a 3-dimensional skull model to simulate clinical conditions of maxillary advancement and loading were recently compared (Araujo et al, 2001). The maximum load sustained at permanent deformation was larger in the infero-superior direction in both groups, while the maximum load for breaking was larger in the antero-posterior direction in both groups. The resorbable polymer fixation system demonstrated lower elastic stiffness compared to titanium fixation yet appears to be adequate for post-operative fixation and able to tolerate the forces of mastication.

Histologic reactions of resorbable polymers have been studied with mixed results (Haers and Sailer, 1998), (Bostman and Pihlajamaki, 2000), (Rokkanen, 2000). No test specifically examined specimens from copolymers of PLLA/PGA yet monomeric PGA samples displayed a non-specific latent foreign body reaction 2-3 months post-operatively in 2 percent of the patients. PLLA monomeric samples have demonstrated contradictory findings ranging from no inflammatory reaction to mild reaction 4-5 years post-operatively. A 2001 case report by Imola et al, demonstrated uncomplicated bone healing in 52 of 54 (96 %) patients stabilized with resorbable PLLA/PGA for midfacial fractures (Imola et al, 2001). These authors recommend the use of resorbable PLLA/PGA as a means of avoiding the potential and well-documented problems with rigid titanium fixation and further support the use of resorbable PLLA/PGA to stabilize fractures and segmental repositioning of the middle and upper craniofacial skeleton.

Likewise, several authors have shown that resorbable PLLA/PGA can be used without post-operative complications for stabilization of zygomaticomaxillary fractures, mandibular fractures, and repair of pediatric craniofacial anomalies (Eppley et al, 1996), (Montag et al, 1997), (Kurpad et al, 2000), (Ashammahki et al, 2001).

Edwards, Kiely, and Eppley have published several long-term studies on the use of resorbable PLLA/PGA for stabilization of routine mandibular bilateral sagittal split osteotomies, genioplasties, and combined maxillary and mandibular orthognathic repositioning surgeries (Edwards et al, 1997), (Edwards et al, 2001). In all cases, the jaw segments were reported as stable up to one year post-operatively. No post-operative complications such as latent foreign body reaction, infection, palpation by the patient, radiographic obstruction, growth restriction or patient request for removal were reported. The authors conclude that resorbable PLLA/PGA can be used for excellent stabilization of all routine orthognathic surgeries without complication.

Most recently Ferretti et al (2002) compared the skeletal stability of forty patients after bilateral sagittal advancement of the mandible. Twenty patients were stabilized with bicortical titanium screws and twenty patients were stabilized with Lactosorb[R] bioabsorbable polymer. No difference in post-operative stability between the two groups after six months and no clinical or radiographic evidence of wound healing difficulties was found. The authors conclude that bioabsorbable fixation is a viable alternative to titanium fixation for mandibular advancements.

Biomechanics of Diverse Facial Patterns

In the 1600s Michelangelo carved a likeness of David in stone that represented a popular conception of beauty. Although perception of beauty is different across cultures, popular trends change only slightly from generation to generation. Although intercultural mixing has altered opinions of beauty, facial balance in three dimensions of space is of cardinal importance to all cultures.

Facial growth patterns and environmental influences on those inherent growth patterns determine facial proportions. Orthodontists have examined the relationship between dental occlusion and skeletal balance with lateral cephalometric radiographs. Edward Angle originally described a classification system of malocclusion in the antero-posterior dimension that is still used today (Angle, 1900). Thousands of basic science and clinical experiments have led most orthodontists today to agree that most antero-posterior imbalances are only symptoms, the cause of which is found in the vertical dimension. Once growth has ceased, any facial imbalances can only be corrected by orthognathic surgery. It is with this premise in mind that the following discussion focuses on the vertical components of the dentofacial complex.

As noted earlier in the introduction, surgical correction with LeFort I impactions and advancements are primarily performed for three distinct problems: skeletal open bite, skeletal Class III anterior cross-bite, and idiopathic hyperdivergent "long-faced" syndrome otherwise known as total maxillary alveolar hyperplasia or vertical maxillary excess. Some patients can manifest all three problems such as the hyperdivergent "long-faced" Class III anterior cross-bite with open bite tendency. The following discussion will examine facial characteristics of the most notable problems and the biomechanical factors they possess that may influence surgical relapse.

First, the dental and facial characteristics of persons with long faces (dolichofacial) can be observed with or without open-bite. According to Bell et al (1977, p. 45) "the upper vertical one-third of the face is usually within normal limits yet examination of the middle vertical one-third (soft tissue nasion - soft tissue subnasale) reveals a narrow nose, narrow alar bases, a prominent nasal dorsum, and depressed paranasal areas". These features give the person a sharp angular look with a prominent nose and "dished-in" cheek areas. The lower vertical one-third (soft tissue subnasale – soft tissue menton) of the face usually shows excessive anterior dental height with more than 4 mm exposure of the maxillary anterior teeth in repose and an extreme (>2mm) amount of maxillary gingiva display when smiling. Anterior open bite typically accompanies this facial appearance. A retruded chin, long lower vertical third, and increased total face height combined with the prominent nasal complex give the person the appearance of the beaked profile of a bird. Functionally, the person cannot close the lips together without muscle strain (lip incompetence) thereby further diminishing facial esthetics and leading to the popular misconception of low intelligence (Fig 10).

Fig 10 Dolichofacial pattern profile and frontal views with lips in repose

Dolichofacial persons exhibit steep mandibular plane angles with large gonial angles and more open skull base flexure. Increased total facial height and lower facial height are coupled with minimal free-way space and canted palatal, occlusal, and mandibular planes (Sassouni, 1964). There is also a predisposition to proclined mandibular incisors and anterior open bites. Additionally, most of the vertical component is found as excess vertical maxillary alveolar growth at both the molar and incisor (Isaacson, 1981). It is also probable that the short mandibular ramus in dolichofacial persons are instrumental in the morphology of the open bite malocclusions commonly seen in these individuals (Sassouni, 1964). Oblique muscle forces from the medial pteygoid, masseter, and temporalis acting posterior to the center of resistance of the molar bite point on the mandible (Fig 11 from Haskell et al, 1986, p. 366) creates a mesial force component between the steep palate and the mandible resulting in weaker bite forces (50 lb) than recorded in brachyfacial patients (150-250 lb). Additionally, Haskell et al (1986) demonstrated that significantly more muscle activation was required in dolichofacial persons (73%) than brachyfacial (32%) persons to produce equivalent bite strengths due to the length of their moment arms.

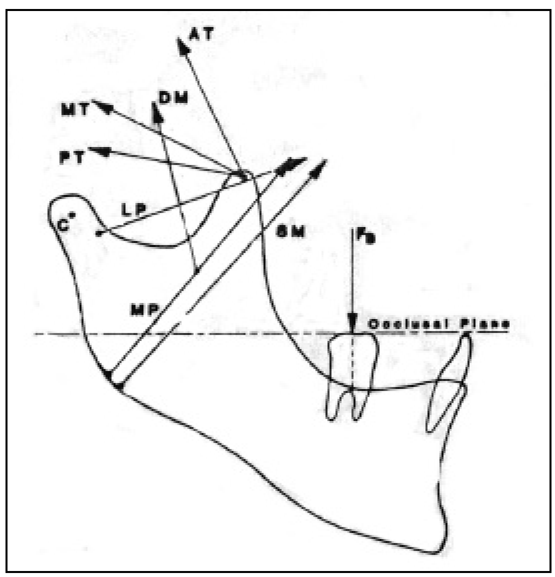

Figure 11 Oblique muscle force vectors of dolichofacial pattern

The mechanical advantage of masticatory muscles is defined as the moment arm of the muscle to the moment arm of the load. Additionally, the moment arm of a muscle is defined as the perpendicular distance from condylion (CO) to the insertion point of the muscle. Fig 12 (Throckmorton, 1980, p. 411) below depicts the moment arm for the masseter muscle (a), temporalis (b), and bite force (c). Smaller bite forces are generated by dolichofacial persons because the moment arm of the load is significantly greater than the moment arm of the masseter and temporalis muscles (Throckmorton, 1980). An increase in the gonial angle from 90 to 155 degrees will decrease the mechanical advantage of the masseter and temporalis muscles of dolichofacial persons by 55 percent.

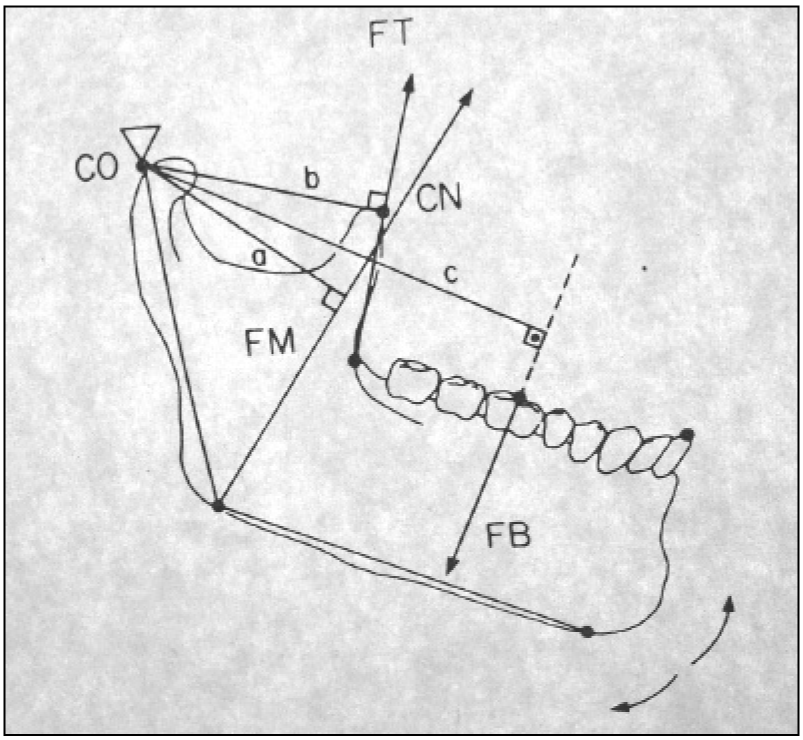

Figure 12 Moment arms from condylion (CO) to molar bite point (FB), temporalis (FT), and masseter (FM)

Next, the brachyfacial person exhibits facial and dental characteristics nearly identical in variation yet opposite in direction to the long-faced dolichofacial person. Brachyfacial individuals also demonstrate a normal upper vertical one-third of the face yet examination of the middle vertical one-third (soft tissue nasion - soft tissue subnasale) reveals a broad nose, flared alar bases, a normal nasal dorum, and prominent rounded paranasal areas. These features give the person a more rounded and robust look. The lower vertical one-third (soft tissue subnasale – soft tissue menton) of the face usually shows decreased anterior dental height with less than 4 mm exposure of the maxillary anterior teeth in repose and no maxillary gingiva display when smiling. A prominent chin, short lower vertical third, and decreased total face height combined with robust paranasal areas give the person a muscle laden appearance to the face. Functionally, the person easily closes the lips together without muscle strain (lip competent) as seen in Figure 13 below.

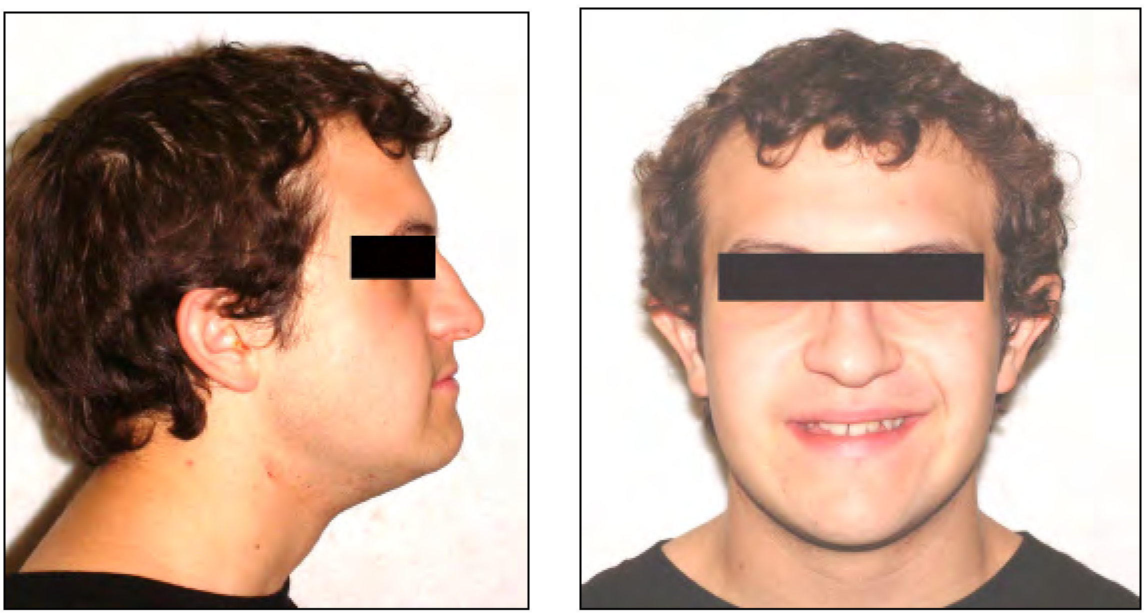

Fig 13 Brachyfacial pattern profile and frontal views with lips in repose

Brachyfacial persons exhibit low mandibular plane angles with small gonial angles and more closed skull base flexures. Decreased total facial height and lower facial height are coupled with additional free-way space and parallel palatal, occlusal, and mandibular planes (Sassouni, 1964). There is also a predisposition to upright or retroclined mandibular incisors and anterior deep bites. Frequently, the maxilla is not sufficient antero-posteriorly for the elongated mandible and an anterior cross bite exists. The anterior cross bite is the most common reason a LeFort I advancement procedure is performed for brachyfacial individuals.

Larger bite forces are generated by brachyfacial persons than dolichofacial persons. Although the moment arm of the load is still greater than the moment arm of the masseter and temporalis muscles in brachyfacial persons, a more favorable ratio exists (fig 14 from Haskell et al, 1986, p. 366).

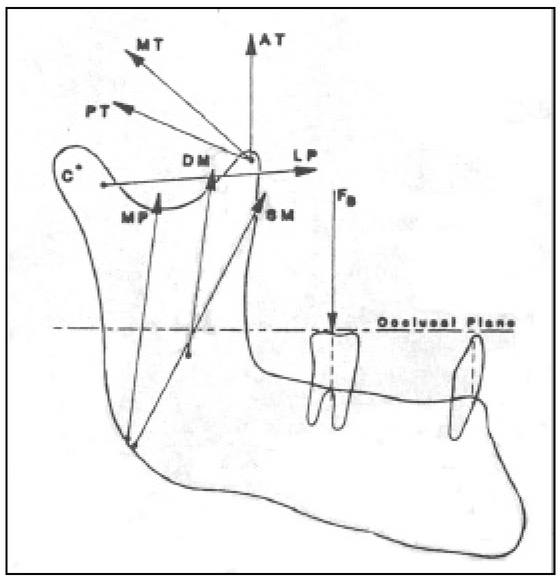

Figure 14 Perpendicular muscle force vectors of brachyfacial pattern

Surgically repositioning the maxilla can alter the moment arms and therefore influence masticatory efficiency and temporomandibular joint (TMJ) reaction forces (Throckmorton, 1985). The calculation of reaction forces from the TMJ using a two muscle model is more sensitive to errors in muscle force direction than muscle force magnitude and no single muscle force vector position produces minimal effect

(Throckmorton, 1985). Most important to this discussion on the magnitude of surgical relapse is the following comment "It is possible that through such analyses, the stresses present in the jaws of diverse mandibular forms may aid in the treatment planning of surgical procedures. Orthognathic sagittal advancements of the mandible that occasionally fail in long-faced persons may be the result of a bony incision unknowingly placed through areas of high stress as pictured in the FEA or caused by inadequate fixation in a highly stressed area prone to relapse as a result of biomechanical failure" (Haskell et al, 1986, p. 380). The magnitude of muscle forces could also factor into the magnitude of relapse after maxillary surgery. Even though muscle patterns and bite forces generated will likely change after orthognathic surgery the muscle volume does not diminish significantly immediately after surgery. Therefore, the larger and more robust masseter and temporalis muscles of brachyfacial individuals may influence post-operative relapse more than dolichofacial individuals through heavier occlusal loads. Likewise, smaller and thinner muscle volumes of dolichofacial persons may not be capable of generating sufficient bite forces to significantly effect surgical relapse of the maxilla.

CHAPTER III

MATERIALS AND METHODS

Institutional Review Board

This study protocol was reviewed and approved by Richard L. Miller, D.D.S., PhD., Chairman of the University of Louisville's Human Studies Committee. In a letter dated December 4, 2001, this retrospective study (613-01) was exempted from further review according to 45 CFR 46.101(b) 4, because information that could identify subjects, and match them with their lateral cephalometric radiographs, was not recorded.

Specific Procedures

This study was designed as a collaborative effort between the University of Louisville School of Dentistry's Department of Graduate Orthodontics in Louisville, KY and Lieutenant Colonel (Dr.) Kevin D. Kiely (US Air Force), chief of oral and maxillofacial surgery at the 82d Dental Squadron located at Sheppard AFB, TX. Twenty-three subjects, 18 with dolichofacial pattern and 5 brachyfacial pattern, ages 19-39 were treated with LeFort I osteotomies to correct excess vertical maxillary height, skeletal anterior open bite, anterior crossbite or combinations thereof. Nine of the twenty-three subjects were female, five with dolichofacial pattern and four with brachyfacial pattern. Nine subjects initially presented with Angle Class II malocclusions, seven of which were skeletal open bite and three simply excess vertical height. Fourteen subjects initially presented with Angle Class III malocclusions, five of which had skeletal open bite, six had anterior crossbite, and three simply excess vertical height.

Pre-operative, immediate post-operative, and one-year post-operative lateral cephalometric radiographs were taken on all twenty-four subjects. All pre-operative, immediate post-operative, and one-year post-operative lateral cephalometric radiographs were traced initially on matte acetate tracing paper (3M Unitek Monrovia, CA) to identify universally accepted cephalometric landmarks. All lateral cephalometric radiographs were then digitized using Ricketts' lateral 71 point analysis with the Dolphin Digital Imaging computer software Version 8.0 (Dolphin Inc., Westwood, CA). A template of each pre-operative maxilla as described by Egbert et al (1995) allowed a best-fit technique of superimposition to be utilized for measurements of the immediate post-operative and one-year post-operative lateral cephalometric radiographs.

Vertical and horizontal reference planes were constructed in order to measure linear millimeter measurements to the following four universally accepted cephalometric landmarks: Posterior nasal spine (PNS), anterior nasal spine (ANS), A-point, and M-point. M-point is defined as the center point in the widest part of the premaxillary outline on the lateral cephalometric radiograph. This point is marked by visual inspection. The horizontal reference plane is defined as Frankfort horizontal from hard tissue porion to orbitale (Po-Or). The vertical reference is defined as a line arising from hard tissue Nasion (N) that is perpendicular to Frankfort horizontal.

Linear millimeter measurements were recorded from the visually located maxillary anterior midpoint (M) as defined by Carpenter, Nanda, and Currier to both reference planes (1989). Point A, anterior nasal spine (ANS), and posterior nasal spine (PNS) were also measured in linear millimeter distances to the same vertical and horizontal reference planes (Fig 15).

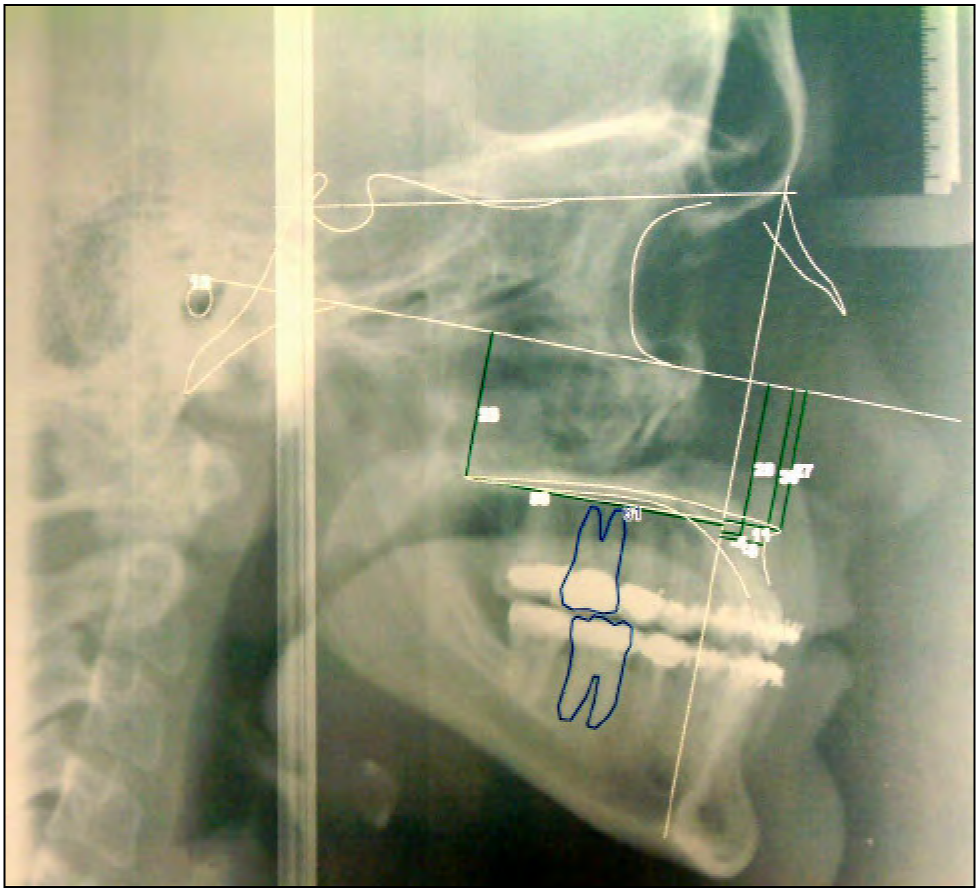

Figure 15 Linear measurements to vertical and horizontal reference planes

The facial pattern of each patient (Fig 16 and 17) was analyzed and calculated according to the following parameters obtained from the pre-operative lateral cephalometric tracing analysis (Rocky Mountain Orthodontics, Canoga Park, CA):

1. Mandibular plane angle- dolichofacial greater than the norm, brachyfacial less than the norm.
2. Mandibular arc- dolichofacial less than the norm, brachyfacial greater than the norm.
3. Lower facial height- dolichofacial greater than the norm, brachyfacial less than the norm.
4. Facial axis- dolichofacial less than the norm, brachyfacial greater than the norm.
5. Ramus height- dolichofacial less than the norm, brachyfacial greater than the norm

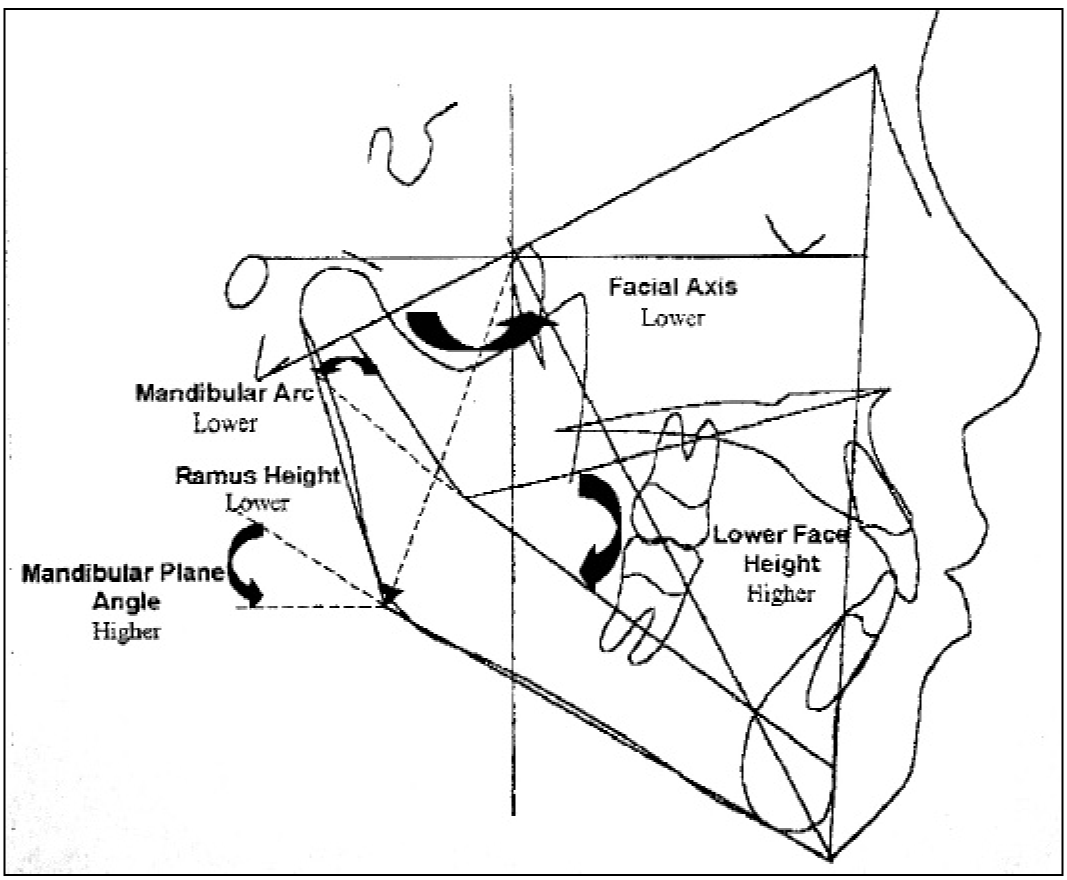

Figure 16 Dolichofacial pattern

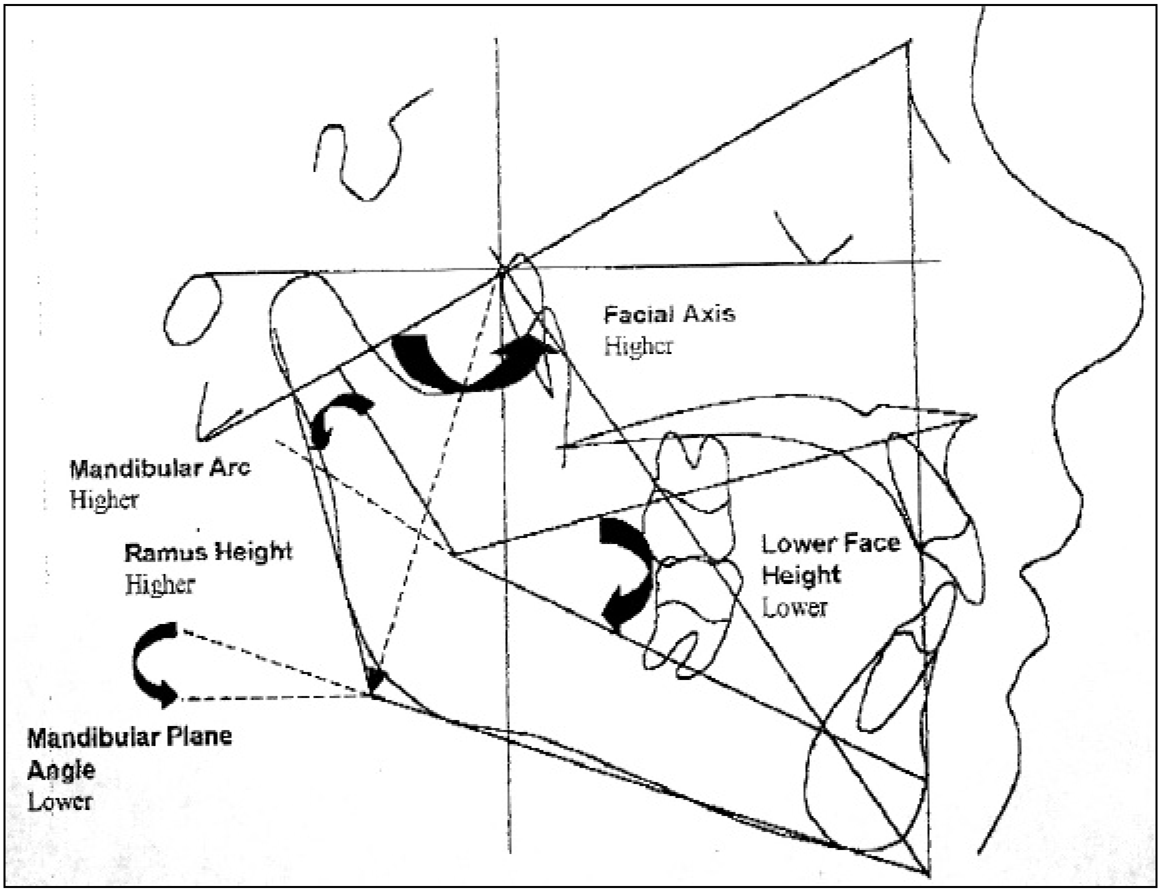

Figure 17 Brachyfacial pattern

Clinical deviations (CD) from the cephalometric norm provided by Dentofacial Planner computer software (Toronto, Ontario, Canada) were calculated and inserted into the following formula to ascertain a facial pattern for each patient:

Facial Pattern= (-CD Lower facial height) + (-CD Mandibular plane angle) + (CD Facial axis) + (CD Ramus height) + (CD Mandibular arc)/5

Statistical Analysis

Based on long-term skeletal relapse data reported by Proffitt et al (1991), Bishara et al (1992), and Egbert et al (1995), a 2.0 mm relapse is considered an unstable one-year post-operative result. Considering the total sample size of 23 patients, a 0.05 level of significance, and a minimum requirement for 0.80+ level of power, the minimum effect size required is 2.0 mm.

A two-factor repeated measures analysis of variance (ANOVA) was used to compare the dolichofacial and brachyfacial groups in the study. Within group and between group comparisons were made for the four horizontal and four vertical assessment points of maxillary relapse used as the dependent measures. Although the bioabsorbable fixation group data cannot be compared directly to a titanium rigid internal fixation group that was not available, inferences to previously published stability data of titanium internal rigid fixation will be made. The significance level was set at 0.05. All resultant data was analyzed with the assistance of the computer generated statistical software package Statistical Program for the Social Sciences (SPSS) for Windows, Version 11.

Consultation on all data entry and other necessary statistical testing requirements was coordinated through Dr. James P. Scheetz, a member of this thesis committee, and Lt Col (Dr.) Kevin D. Kiely, the chief collaborator for this study.

CHAPTER IV

RESULTS

Vertical Measurement Descriptive Statistics

Analysis of the linear measurements for all subjects made from the four points of the maxilla (PNS, M-point, A-point, and ANS) to Frankfort horizontal plane revealed differential surgical movement. Table 1 provides mean and standard deviation descriptive statistics of linear millimeter measurements of the pre-operative (1) and immediate post-operative (2) lateral cephalometric radiographs of both groups to describe the magnitude of surgical movement.

	PNS1	PNS2	M1	M2	A1	A2	ANS1	ANS2
Dol Mean	26.22	25.87	29.95	28.52	30.60	29.11	23.83	22.55
Dol Std Dev	2.399	2.767	3.358	4.290	3.852	4.897	3.638	4.350
Brac Mean	24.91	24.27	26.60	26.84	26.97	27.21	22.01	22.26
Brac Std Dev	2.967	4.395	5.457	6.694	6.513	8.449	5.232	7.146

Table 1 Vertical measurements from pre-operative to immediate post-operative

Descriptive statistics for the mean and standard deviation from immediate post-operative (2) to one year post-operative (3) are shown in Table 2. The difference between the immediate post-operative measurement and one year post-operative measurement describes the magnitude of relapse in the vertical direction for both groups in the study.

	PNS2	PNS3	M2	M3	A2	A3	ANS2	ANS3
Dol Mean	25.87	25.83	28.52	28.43	29.11	29.10	22.55	22.38
Dol Std Dev	2.767	2.727	4.290	4.187	4.897	4.721	4.350	4.350
Brac Mean	24.27	23.93	26.84	26.54	27.21	27.19	22.26	22.26
Brac Std Dev	4.395	4.197	6.694	7.179	8.449	8.581	7.146	7.146

Table 2 Vertical measurements from immediate post-operative to one-year post-operative

The magnitude of post-operative relapse in millimeters for the four vertical measurements is shown in Table 3 below. Post-operative relapse is defined as the magnitude of linear maxillary movement towards the pre-operative state.

	PNS - FH	M-Point - FH	A-Point - FH	ANS - FH
Dolichofacial	0.033	0.096	0.069	0.168
Brachyfacial	0.340	0.302	0.026	0.202
All Subjects	0.1	0.141	0.06	0.088

Greatest magnitude values for each group are shown in red

Table 3 Magnitude of post-operative relapse in the vertical direction

Vertical Measurement- PNS to Frankfort Horizontal

Analysis of the vertical measurement PNS to Frankfort horizontal using a within group ANOVA test (Wilks' Lambda) revealed a statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects and by face type (Table 4).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.600	6.674	2.000	20.000	.006
By Face Type	.742	3.484	2.000	20.000	.050

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 4 Multivariate tests for PNS-Frankfort horizontal

Similarly, pairwise comparisons revealed a statistically significant difference from immediate post-operative to one year post-operative (Table 5).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	.496	.466	.300
Pre-op to One Year Post-op	.682	.442	.138
Immed Post-op to One Year Post-op	.187	.066	.011

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 5 Pairwise comparisons for PNS to Frankfort horizontal

No statistically significant difference was found between the two groups in post-operative relapse for the point PNS to Frankfort horizontal as shown in Table 6.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	30.187	1	30.187	1.289	.269

Table 6 Test of Between-Subject Effects for PNS to Frankfort horizontal

Figures 18 (dolichofacial) and 19 (brachyfacial) pictorially describe the within group variation for the vertical linear measurement PNS to Frankfort horizontal.

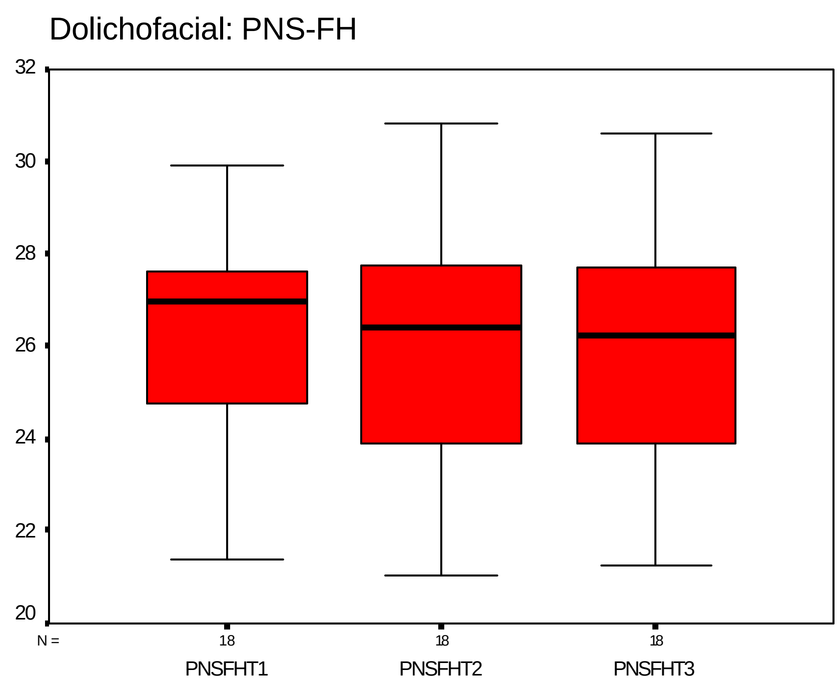

Figure 18 Vertical measurement PNS to Frankfort horizontal for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

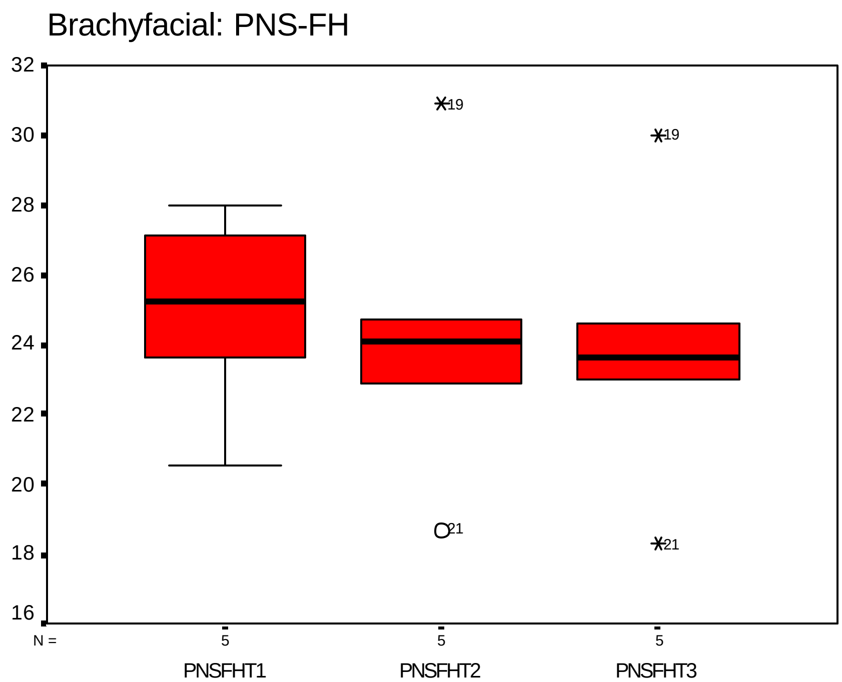

Figure 19 Vertical measurement PNS to Frankfort horizontal for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Vertical Measurement- M-point to Frankfort Horizontal

Analysis of the vertical measurement M-point to Frankfort horizontal using a within groups ANOVA test (Wilks' Lambda) revealed a statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects but no statistically significant difference was found when examined by face type (Table 7).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.716	3.963	2.000	20.000	.036
By Face Type	.915	.925	2.000	20.000	.413

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 7 Multivariate tests for M-point to Frankfort horizontal

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 8).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	.591	.798	.849
Pre-op to One Year Post-op	.790	.774	.684
Immed Post-op to One Year Post-op	.199	.084	.080

Table 8 Pairwise comparisons for measurement from M-point to Frankfort horizontal

No statistically significant difference was found between the two groups in post-operative relapse for M-point to Frankfort horizontal as shown in Table 9.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	62.489	1	62.489	1.107	.305

Table 9 Test of Between-Subject Effects for M-point to Frankfort horizontal

Figures 20 (dolichofacial) and 21 (brachyfacial) pictorially describe the within groups variation for the vertical linear measurement M-point to Frankfort horizontal.

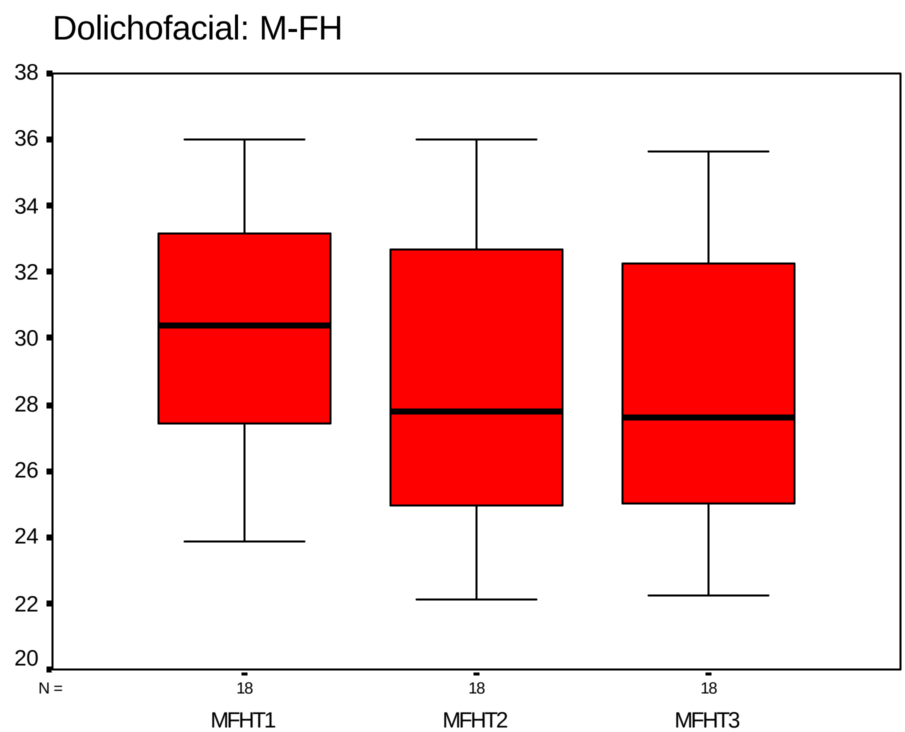

Figure 20 Vertical measurement M-point to Frankfort horizontal for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

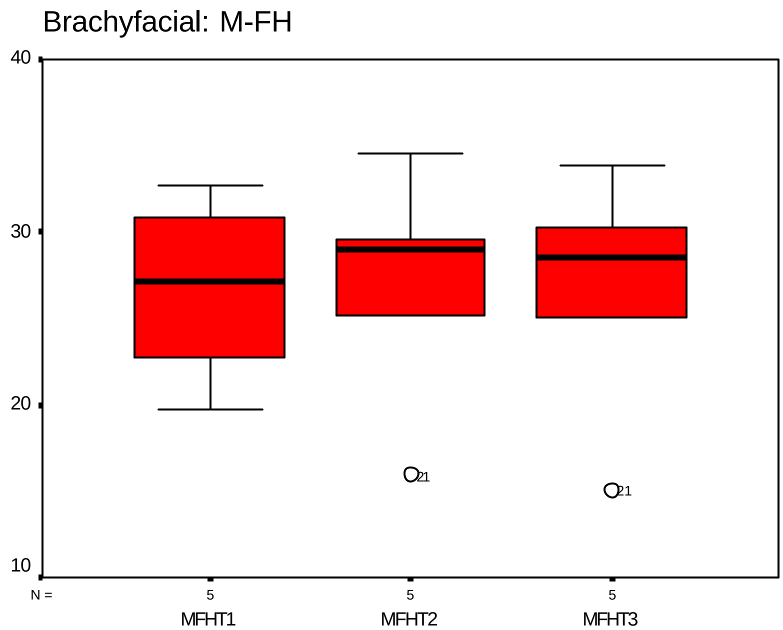

Figure 21 Vertical measurement M-point to Frankfort horizontal for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Vertical Measurement- A-point to Frankfort Horizontal

Analysis of the vertical measurement A-point to Frankfort horizontal using a within groups ANOVA test (Wilks' Lambda) revealed no statistically significant differences from immediate post-operative to one-year post-operative when evaluated for all subjects and by face type (Table 10).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.918	.888	2.000	20.000	.427
By Face Type	.905	1.050	2.000	20.000	.368

Table 10 Multivariate tests for A-Point to Frankfort horizontal

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 11).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	.593	.798	.834
Pre-op to One Year Post-op	.641	.720	.765
Immed Post-op to One Year Post-op	0.0047	.098	.951

Table 11 Pairwise comparisons for measurement from A-point to Frankfort horizontal

No statistically significant difference was found between the two groups in post-operative relapse for A-point to Frankfort horizontal as shown in Table 12.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	73.602	1	73.602	.928	.346

Table 12 Test of Between-Subject Effects for A-point to Frankfort horizontal

Figures 22 (dolichofacial) and 23 (brachyfacial) pictorially describe the within groups variation for the vertical linear measurement A-point to Frankfort horizontal.

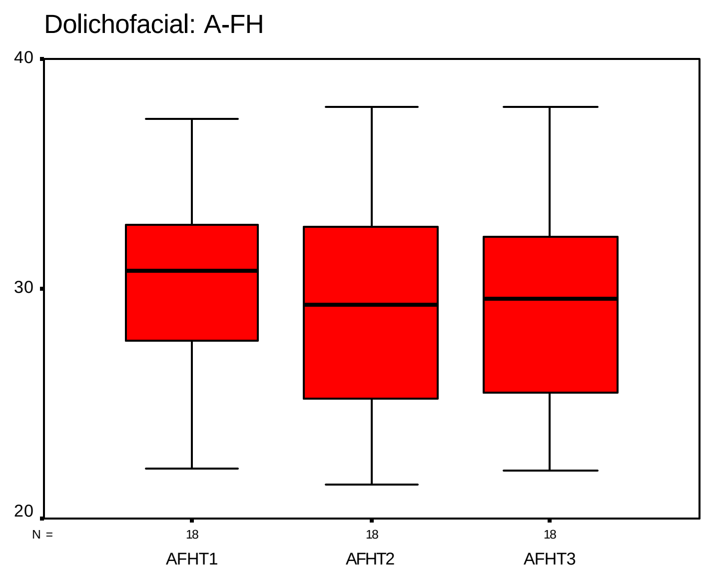

Figure 22 Vertical measurement A-point to Frankfort horizontal for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

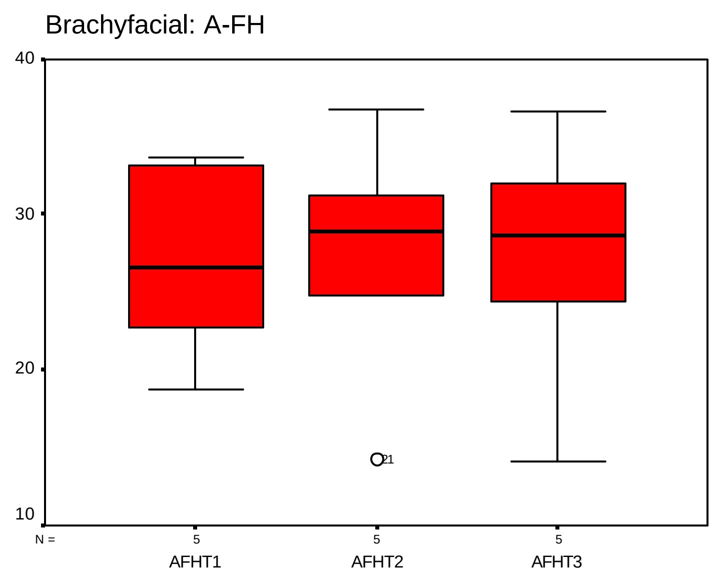

Figure 23 Vertical measurement A-point to Frankfort horizontal for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Vertical Measurement- ANS to Frankfort Horizontal

Analysis of the vertical measurement ANS to Frankfort horizontal using a within groups ANOVA test (Wilks' Lambda) revealed no statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects and by face type (see Table 13).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.885	1.303	2.000	20.000	.294
By Face Type	.950	.522	2.000	20.000	.601

Table 13 Multivariate tests for ANS-Frankfort horizontal

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 14).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	.516	.740	.870
Pre-op to One Year Post-op	.701	.721	.716
Immed Post-op to One Year Post-op	.185	.142	.502

Table 14 Pairwise comparisons for measurement from ANS to Frankfort horizontal

No statistically significant difference was found between the two groups in post-operative relapse for the point ANS to Frankfort horizontal as shown in Table 15.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	7.636	1	7.636	.128	.724

Table 15 Test of Between-Subject Effects for ANS to Frankfort horizontal

Figures 24 (dolichofacial) and 25 (brachyfacial) pictorially describe the within groups variation for the vertical linear measurement ANS to Frankfort horizontal.

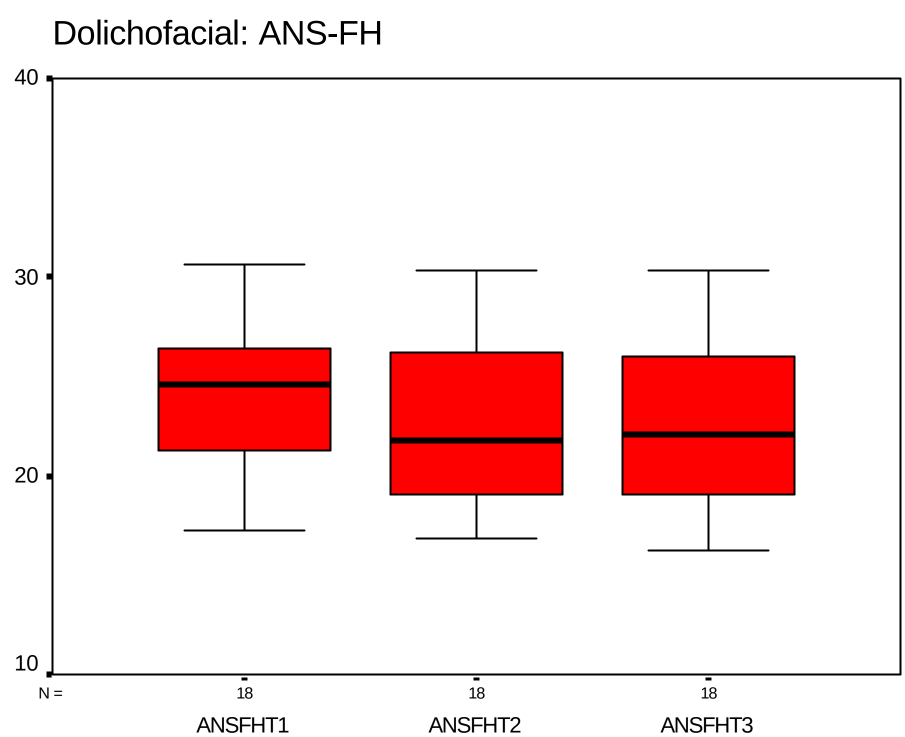

Figure 24 Vertical measurement ANS to Frankfort horizontal for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

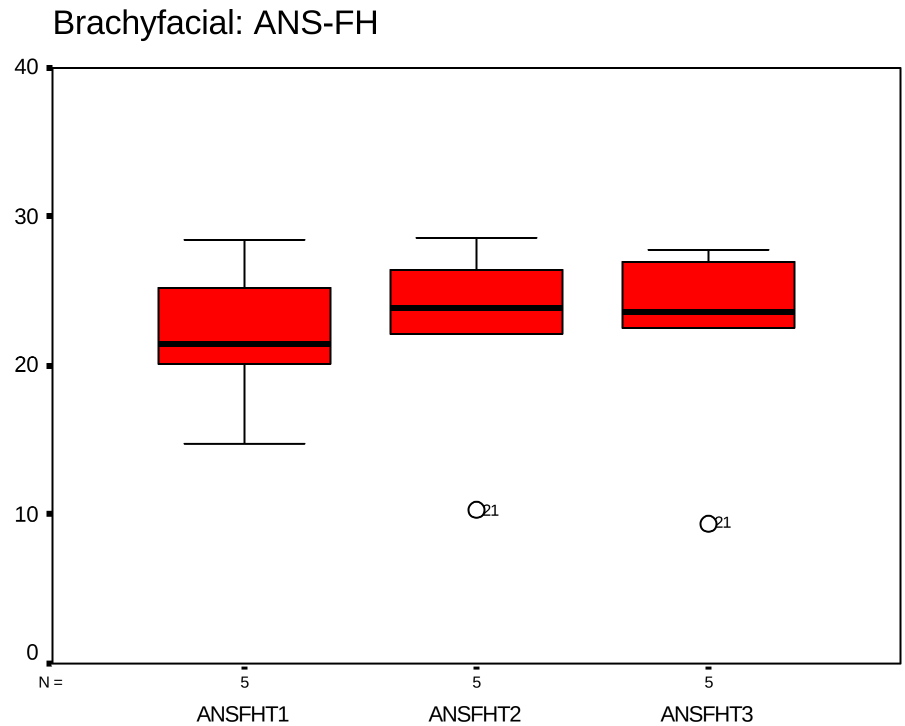

Figure 25 Vertical measurement ANS to Frankfort horizontal for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Horizontal Measurement Descriptive Statistics

Analysis of the linear measurements for all subjects made from the four points of the maxilla (PNS, M-point, A-point, and ANS) to a Nasion perpendicular plane describes the magnitude of maxillary movement in the horizontal direction. Table 16 provides mean and standard deviation descriptive statistics of linear millimeter measurements of the pre-operative (1) and immediate post-operative (2) lateral cephalometric radiographs of both groups to describe the magnitude of surgical movement.

	PNS1	PNS2	M1	M2	A1	A2	ANS1	ANS2
Dol Mean	46.26	44.48	-3.93	-1.65	-.152	1.91	4.21	6.149
Dol Std Dev	3.499	4.769	6.944	5.094	4.970	3.924	4.472	4.90
Brac Mean	43.876	38.752	1.104	3.25	3.60	7.428	6.30	10.06
Brac Std Dev	1.807	3.234	4.356	2.009	2.742	2.843	3.112	2.976

Table 16 Horizontal measurements from pre-operative to immediate post-operative

Descriptive statistics for the mean and standard deviation from immediate post-operative (2) to one year post-operative (3) are shown in Table 17. These measurements describe the magnitude of relapse in the horizontal direction for both groups in the study.

	PNS2	PNS3	M2	M3	A2	A3	ANS2	ANS3
Dol Mean	44.48	44.31	-1.65	-1.73	1.91	1.90	6.149	5.88
Dol Std Dev	4.769	4.297	5.094	5.167	3.924	3.893	4.90	3.886
Brac Mean	38.752	39.05	3.25	3.07	7.428	7.23	10.06	9.88
Brac Std Dev	3.234	3.048	2.009	1.628	2.843	2.327	2.976	2.840

Table 17 Horizontal measurements from immediate post-operative to one-year post-operative

The magnitude of post-operative relapse in millimeters for the four horizontal measurements is shown in Table 18 below. Post-operative relapse is defined as the magnitude of linear maxillary movement towards the pre-operative state.

	PNS – N Perp	M-Point – N Perp	A-Point – N Perp	ANS – N Perp
Dolichofacial	0.164	0.084	0.009	0.269
Brachyfacial	0.3	0.188	0.198	0.178
All Subjects	0.062	0.106	0.051	0.249

Greatest magnitude values for each group are shown in red

Table 18 Magnitude of post-operative relapse in the horizontal direction

Horizontal Measurement- PNS to Nasion Perpendicular

Analysis of the horizontal measurement PNS to Nasion perpendicular using a within groups ANOVA test (Wilks' Lambda) revealed a statistically significant difference from immediate post-operative to one year post-operative when evaluated for all subjects yet no statistically significant difference was seen by face type (Table 19).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.485	10.631	2.000	20.000	.001
By Face Type	.880	1.361	2.000	20.000	.279

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 19 Multivariate tests for PNS-Nasion perpendicular

Pairwise comparisons revealed no statistically significant differences from immediate post-operative to one year post-operative (Table 20).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	3.453	.996	.007
Pre-op to One Year Post-op	3.385	.853	.002
Immed Post-op to One Year Post-op	0.0068	.214	.985

Table 20 Pairwise comparisons for measurement from PNS to Nasion perpendicular

A statistically significant difference was found between the two groups in post-operative relapse for the point PNS to Nasion perpendicular as shown in Table 21. Brachyfacial subjects demonstrated more post-operative relapse than dolichofacial subjects when comparing the absolute linear values in Tables 18 and 21

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	233.510	1	233.510	6.072	.022

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 21 Test of Between-Subject Effects for PNS to Nasion perpendicular

Figures 26 (dolichofacial) and 27 (brachyfacial) pictorially describe the within groups variation for the horizontal linear measurement PNS to Nasion perpendicular.

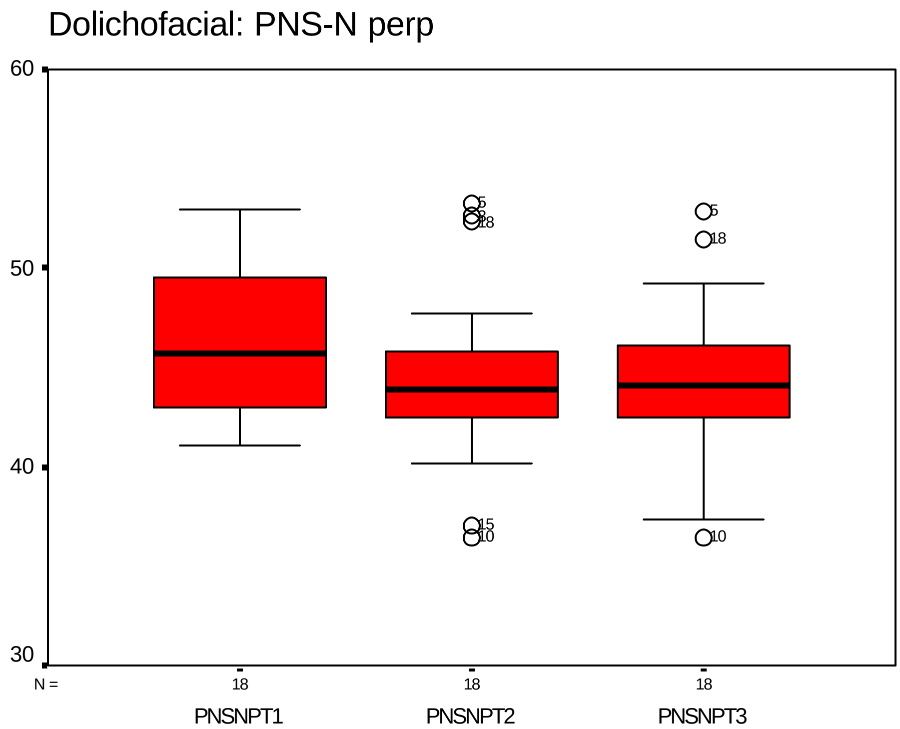

Figure 26 Horizontal measurement PNS to Nasion perpendicular for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

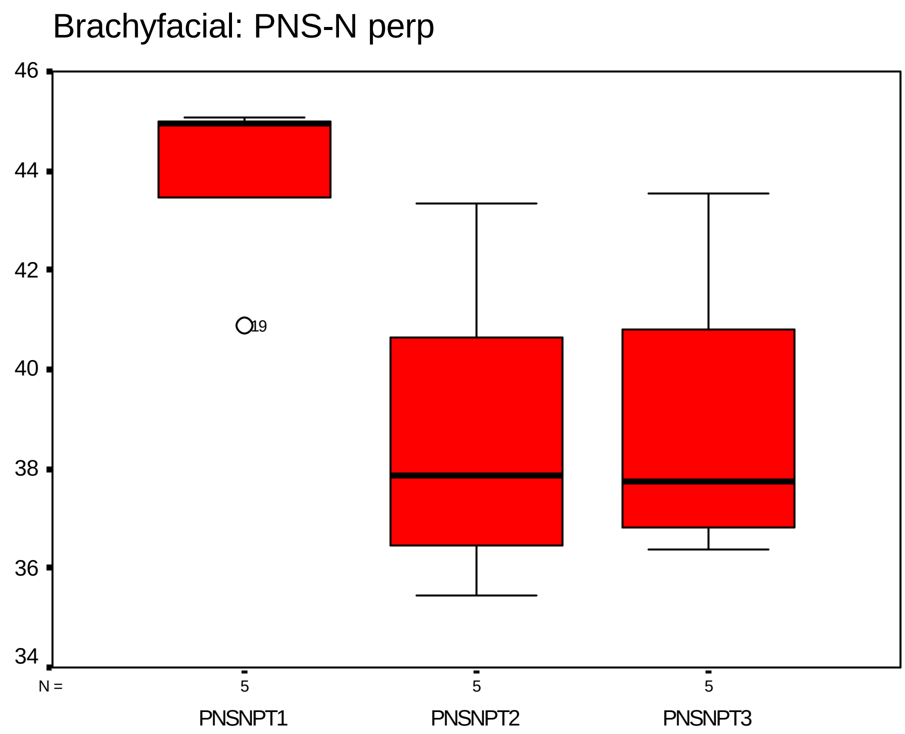

Figure 27 Horizontal measurement PNS to Nasion perpendicular for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Horizontal Measurement- M-point to Nasion perpendicular

Analysis of the horizontal measurement M-point to Nasion perpendicular using a within groups ANOVA test (Wilks' Lambda) revealed no statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects and by face type (Table 22).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.851	1.751	2.000	20.000	.199
By Face Type	.987	.129	2.000	20.000	.880

Table 22 Multivariate tests for M-point to Nasion perpendicular

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 23).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	2.217	1.169	.200
Pre-op to One Year Post-op	2.082	1.087	.193
Immed Post-op to One Year Post-op	.136	.141	.719

Table 23 Pairwise comparisons for measurement from M-point to Nasion perpendicular

No statistically significant difference was found between the two groups in post-operative relapse for M-point to Nasion perpendicular as shown in Table 24.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	283.737	1	283.737	3.879	.062

Table 24 Test of Between-Subject Effects for M-point to Nasion perpendicular

Figures 28 (dolichofacial) and 29 (brachyfacial) pictorially describe the within groups variation for the horizontal linear measurement M-point to Nasion perpendicular.

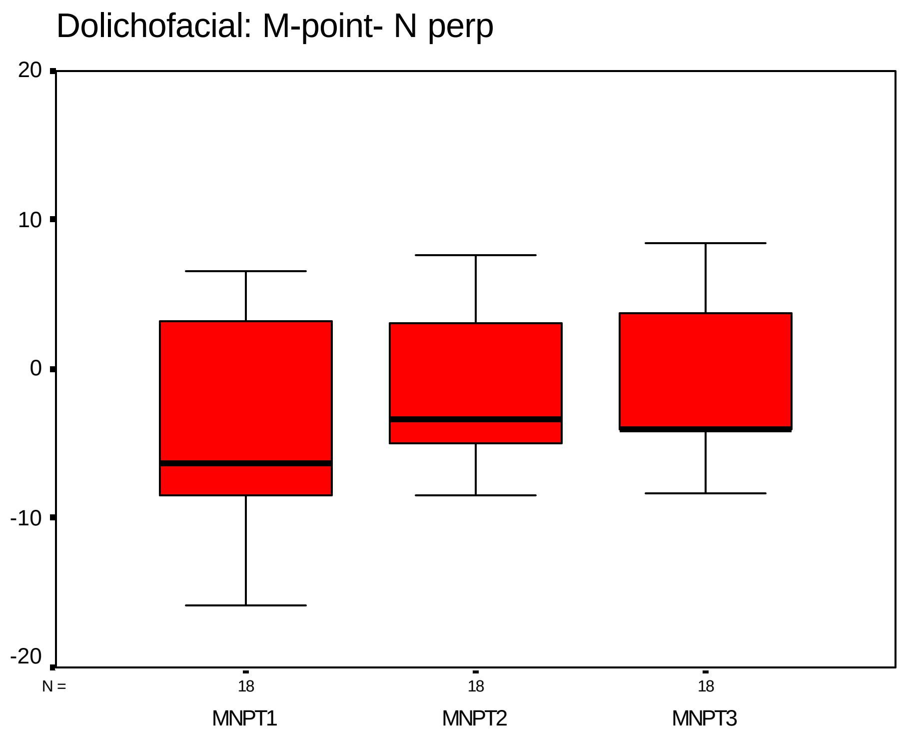

Figure 28 Horizontal measurement M-point to Nasion perpendicular for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

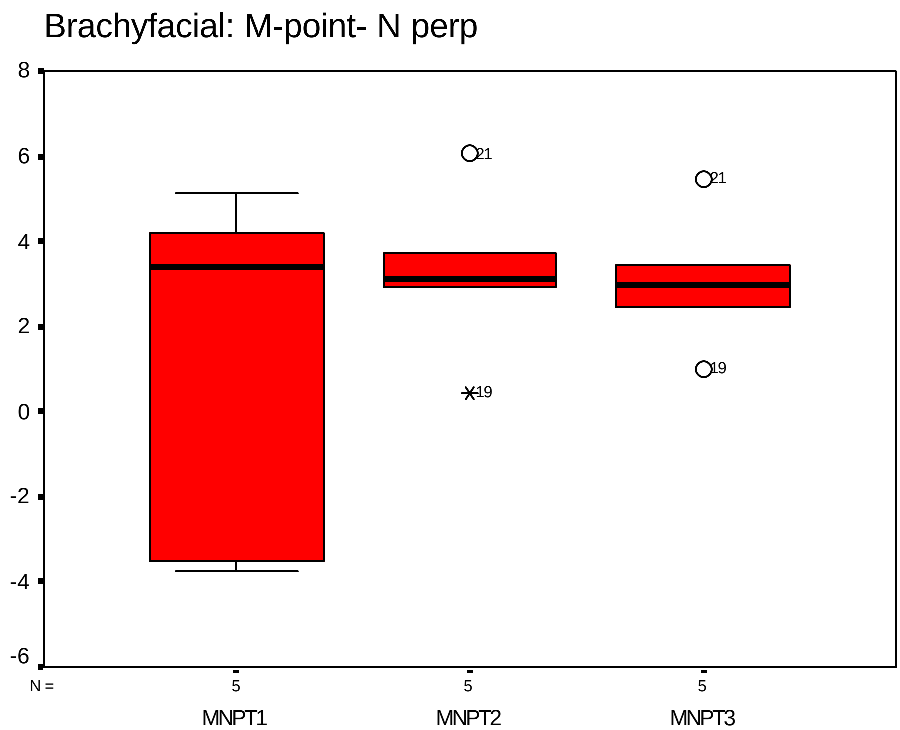

Figure 29 Horizontal measurement M-point to Nasion perpendicular for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Vertical Measurement- A-point to Nasion perpendicular

Analysis of the horizontal measurement A-point to Nasion perpendicular using a within groups ANOVA test (Wilks' Lambda) revealed a statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects yet no statistically significant difference when examined by face type (Table 25).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.663	5.074	2.000	20.000	.017
By Face Type	.963	.387	2.000	20.000	.684

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 25 Multivariate tests for A-point to Nasion perpendicular

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 26).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	2.946	.986	.021
Pre-op to One Year Post-op	2.842	.906	.015
Immed Post-op to One Year Post-op	.104	.150	.872

Table 26 Pairwise comparisons for measurement from A-point to Nasion perpendicular

A significant difference was found between the two groups in post-operative relapse for the point A-point to Nasion perpendicular as shown in Table 27.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	277.844	1	277.844	7.076	.015

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 27 Test of Between-Subject Effects for A-point to Nasion perpendicular

Figures 30 (dolichofacial) and 31 (brachyfacial) pictorially describe the within groups variation for the horizontal linear measurement A-point to Nasion perpendicular.

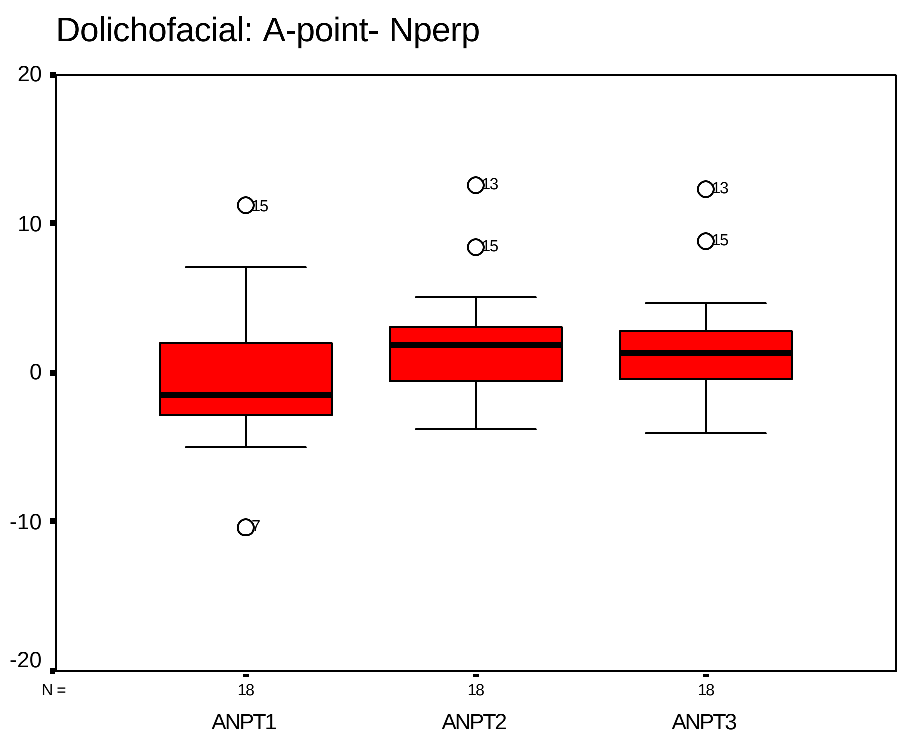

Figure 30 Horizontal measurement A-point to Nasion perpendicular for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

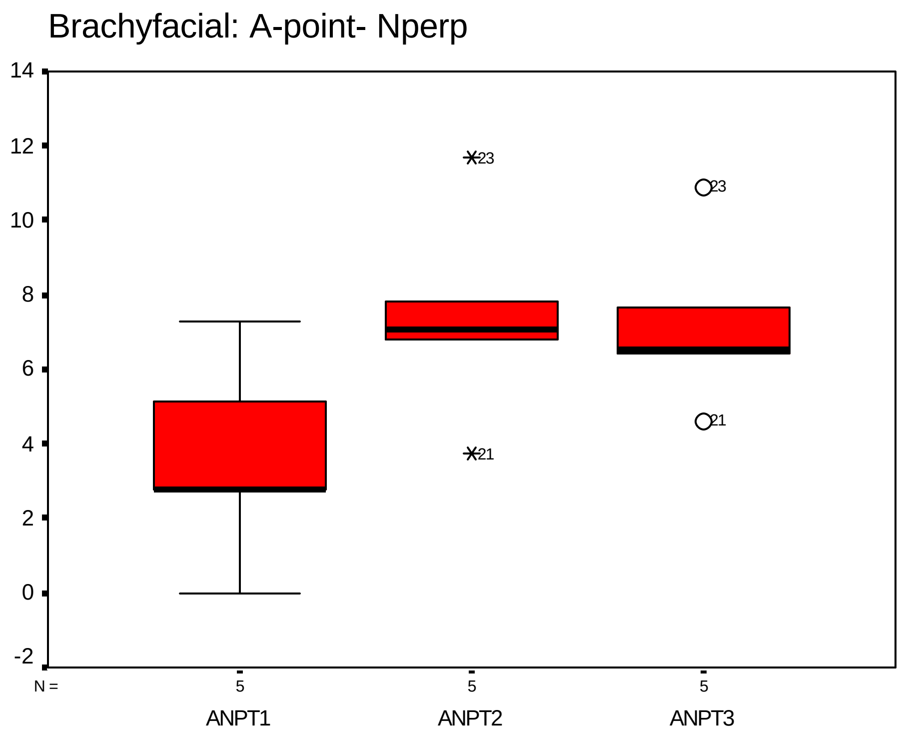

Figure 31 Horizontal measurement A-point to Nasion perpendicular for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

Horizontal Measurement- ANS to Nasion Perpendicular

Analysis of the horizontal measurement ANS to Nasion perpendicular using a within groups ANOVA test (Wilks' Lambda) revealed a statistically significant difference from immediate post-operative to one-year post-operative when evaluated for all subjects yet no statistically significant difference when examined by face type (Table 28).

	Wilks' Lambda	F	Hypothesis df	Error df	Sig.
All Subjects	.697	4.339	2.000	20.000	.027
By Face Type	.862	1.604	2.000	20.000	.226

Values in red are greater than or equal to p= 0.05. Therefore, reject the null hypothesis (H_0)

Table 28 Multivariate tests for ANS to Nasion perpendicular

Pairwise comparisons revealed no statistically significant difference from immediate post-operative to one year post-operative (Table 29).

Comparison	Mean Difference	Std. Error	Sig.
Pre-op to Immed Post-op	2.847	.948	.020
Pre-op to One Year Post-op	2.623	.869	.020
Immed Post-op to One Year Post-op	.224	.115	.186

Table 29 Pairwise comparisons for measurement from ANS to Nasion perpendicular

No statistically significant difference was found between the two groups in post-operative relapse for the point ANS to Nasion perpendicular as shown in Table 30.

	Type III Sum of Squares	df	Mean Square	F	Sig.
Face Type	130.296	1	130.296	3.399	.079

Table 30 Test of Between-Subject Effects for ANS to Nasion perpendicular

Figures 32 (dolichofacial) and 33 (brachyfacial) pictorially describe the within groups variation for the horizontal linear measurement ANS to Nasion perpendicular.

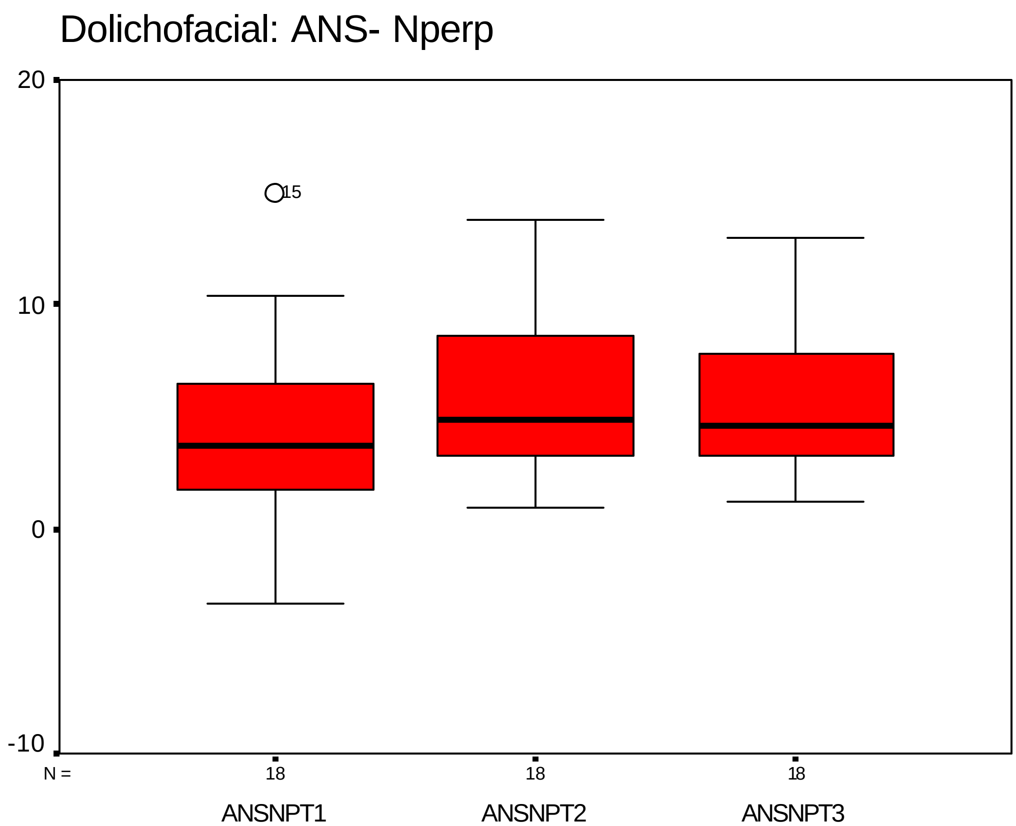

Figure 32 Horizontal measurement ANS to Nasion perpendicular for Dolichofacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

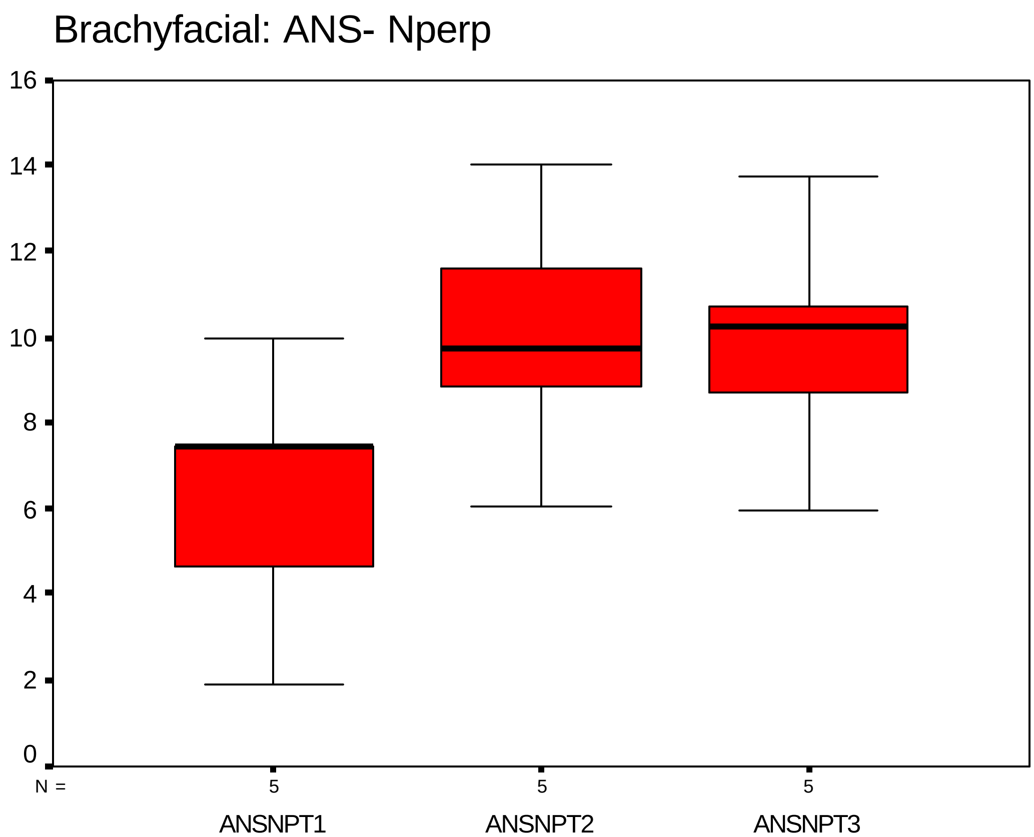

Figure 33 Horizontal measurement ANS to Nasion perpendicular for Brachyfacial pattern

- Shaded area (box) represents the range containing 50 percent of the measured values.
- Horizontal line across the box area represents the median value.
- Lines (whiskers) extend from the box area to highest and lowest values, excluding outliers.
- Cases lying outside high and low range of values represent outliers.

CHAPTER V

DISCUSSION

It is important to note that although the overall sample size was adequate to analyze post-operative relapse, we must acknowledge that the small number of brachyfacial subjects clearly limits ones ability to draw appropriate conclusions about the differences in biomechanical efficiency upon post-operative stability.

The results of this study show statistically significant post-operative relapse for all subjects for the vertical measurements PNS and M-point to Frankfort horizontal. A pairwise comparison of M-point to Frankfort horizontal, however, revealed no statistically significant difference from immediate post-operative to one year post-operative. Only point PNS showed a statistically significant difference between the two facial types (dolichofacial vs brachyfacial) for any of the vertical measurements. The results appear to show statistically greater post-operative relapse for PNS to Frankfort horizontal than the other three points in this study which contrasts with the findings of earlier studies (Proffit et al, 1987) which reported greater relapse of the anterior maxilla in a superior direction.

Antero-posterior relapse was statistically significant using the two-factor repeated measures ANOVA (Wilks' lambda) for all subjects for PNS, A-point, and ANS to Nasion perpendicular. Pairwise comparisons of A-point and ANS to Nasion perpendicular, however, revealed no statistically significant differences from immediate post-operative to one year post-operative. A statistically significant difference was found between the two facial types (dolichofacial vs brachyfacial) for points PNS and A-point to Nasion perpendicular with brachyfacial subjects demonstrating more post-operative relapse.

The most clinically important findings of this study are found in the descriptive statistics from immediate post-operative to one year post-operative. Although no direct comparison can be made to rigid internal metallic fixation, the absolute linear measurements accurately depict the magnitude of post-operative relapse found in this population. For all subjects, the greatest relapse in the superior direction was 0.141 mm at M-point. Dolichofacial individuals showed more relapse at ANS (0.168 mm) than any other point while brachyfacial subjects demonstrated more post-operative vertical relapse at PNS (0.340 mm) with M-point closely following (0.302 mm). Antero-posteriorly, the greatest relapse for all subjects was 0.249 mm at ANS. Dolichofacial subjects showed more relapse at ANS (0.269 mm) while brachyfacial individuals showed more relapse at PNS (0.30 mm). Brachyfacial subjects showed more horizontal relapse than dolichofacial subjects for three out of the four points. As stated earlier, although no direct comparison to rigid internal metallic fixation can be made the most germane addition to the body of post-operative stability literature can be found in the magnitudes of linear relapse. Earlier findings by Proffit et al (1991) reported that 20% of their subjects had 2-4 mm of posterior movement of the anterior maxillary landmarks using a 2 mm relapse threshold as minimally acceptable.

The findings of this study demonstrate relapse tendencies in fractions of a millimeter which can perhaps be attributed to excellent surgical manipulation, fixation material, or both. Although several relapse values for this study may have been statistically significant the absolute magnitude was clinically insignificant. In fact, post-operative relapse was less than that previously published for rigid internal metallic fixation (Egbert et al, 1995), (Hoffman and Moloney, 1996).

A surgical orthodontic treatment plan is only as good as the magnitude of relapse a patient experiences. Excellent post-operative stability of LeFort I osteotomies has been reported by numerous authors (Luyk and Ward-Booth, 1985), (Bishara et al, 1988), (Ellis et al, 1989), (Larsen et al, 1989), (Louis et al, 1993), (Bailey et al, 1994), and (Egbert et al, 1995). Metallic fixation has proven to be equivalent or superior to both MMF wire fixation and internal wire osteosynthesis fixation (Larsen et al, 1989), (Egbert et al, 1995) yet Wall et al (1998) concluded that titanium mini-plates did not prevent post-operative migration of the osteotomy segment and post-operative migration of the osteotomy segment indicates that outcome predictions of surgical corrections are uncertain.

Metallic devices permanently implanted in the human body are not without complication. Metallic fixation systems may require removal due to loosening, migration, dental impingement, interference with the maxillary sinuses leading to sinus infections, palpability through the skin of the face, thermal sensitivity, latent foreign body reactions and infections, and patient’s psychological desire to eliminate artificial hardware (Schmidt et al, 1998). Are we certain that the metals used in modern orthognathic surgery today are entirely biologically inert?

Progress has never been made in any endeavor, particularly orthognathic surgery by accepting the status quo. A goal for this study was to safely and effectively reposition and restore the facial bones with limited facial scars, artificial materials, and post-operative relapse. Excellent post-operative stability and esthetics without permanently implanted hardware is clearly a lofty goal. I believe this goal was achieved with the bioabsorbable polymer Lactosorb^{R}.

Examining post-operative stability without evaluating the potential effects of diverse skeletal facial patterns on relapse is incomplete. The small sample of brachyfacial subjects was clearly a limitation. Further evaluation of the biomechanical effects of diverse facial patterns using larger sample sizes may further illuminate our understanding of why certain subjects relapse more than others after LeFort I osteotomies or other types of orthognathic surgery.

CHAPTER VI

CONCLUSION

Statistically greater post-operative relapse for PNS to Frankfort horizontal than the other three points in this study was found for all subjects when evaluated for vertical stability. Antero-posterior relapse for all subjects was again only statistically significant for the point PNS. The only statistically significant differences found between the two facial types (dolichofacial vs brachyfacial) was PNS to Frankfort horizontal and PNS and A-point to Nasion perpendicular with brachyfacial subjects demonstrating more post-operative relapse. Further studies using larger sample sizes of diverse facial patterns are required to determine the precise role biomechanical efficiency plays in surgical relapse.

Although several values were found to be statistically significant for all subjects, the absolute values of post-operative relapse using bioabsorbable polymers (Lactosorb^{R}) were clinically negligible. The most significant contribution of this study to the volume of surgical stability literature is reporting the absolute magnitudes of post-operative relapse. The greatest relapse in any direction was 0.340 mm (PNS to Frankfort horizontal). Bioabsorbable copolymers provide excellent post-operative stability for superior and anterior maxillary surgical repositioning that rivals stability measurements using rigid internal metallic fixation. Considering the potential for post-operative complications with metallic fixation and the apparent equality of resorbable and metallic biomaterials for post-operative stabilization, one can easily foresee bioabsorbables replacing metallic fixation as the “gold standard” for orthognathic surgery.

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Diploma, Air Command and Staff College
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Commendation Medal, USAF, 2001.

Health Professions Scholarship, USAF, 1996.

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NATIONAL MEETING PRESENTATIONS: Increasing Alveolar Ridge Height Using A Resorbable Distraction Device. 1999 Thomas P. Hinman Dental Symposium Table Clinic, Atlanta, GA.

QCT Measured Masseter Muscle Cross Sectional Area. 1997 American Association for Dental Research, Orlando, FL.

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